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## ORIGINAL ARTICLES.

### The Base of the Devonian, with special reference to the Welsh Borderland.

By L. Dudley Stamp, B.A., D.Sc., A.K.C., F.G.S.

(*Concluded from p. 372.*)

(iii) Perton, near Stoke Edith (Here. XXXIV, S.E.). A fairly continuous section is here seen just above the cottages on the east side of the road :—

Soft, brown or grey micaceous shales full of plant-remains and with bands of false-bedded sandstone. Some of the latter are full of carbonized fragments of plants (including *Pachytheca*) and Eurypterids (including *E. problematicus*). Just above the base is a thin sandstone band with claystone pebbles. A few fish-spines occurred at this horizon.

*Chonetes* Beds.—Irregularly bedded calcareous flagstones with numerous fossils (33, 34, 36, 46, 50 and other lamellibranchs, 54, 57).

The *Chonetes* Beds are not evenly bedded like the Upper *Chonetes* Beds of Clun Forest, and suggest a lower horizon. *Chonetes striatella* itself ranges down a long way, and in Perton Quarry (500 yards to the south of the above section) is found associated with *Atrypa reticularis*, *Strophomena euglypha*, and other fossils suggesting the horizon of the Aymestry Limestone.

(iv) Tarrington (Here. XXXIV, S.E., and XXXV, S.W.). There is an old quarry in Downton Sandstone, about 600 yards south-west of the church, in which are exposed about 7 feet of false-bedded yellowish sandstones full of plant fragments, *Lingula cornea*, and fish-remains. The latter include large fin-spines of 20 (?), 4a, 7, 22, and some small black, spine-like bodies which may be referable to *Birkenia*, as well as large indeterminable bone-fragments. About the middle of the section is a very coarse bed with carbonized fragments up to 2 inches in length. *Pachytheca* occurs in this bed. There are also some bands of grey clay. In a quarry to the south-west of Hill Farm typical fossiliferous *Chonetes* Beds are exposed. About 6 feet from the top on the northern side a thin band, about one-sixteenth of an inch thick, consisting of broken shells, has very much the appearance of a bone-bed. At the bend in the lane immediately east of Hill Farm typical *Chonetes* Beds are

seen to be succeeded abruptly by micaceous tilestones, grey shale, and coarse conglomerate. The latter is sufficiently rich in fish-remains to be called a bone-bed (1, 4a, 7, 60, etc.).

(v) Rushall (Here. XLI, S.W.). Good sections are visible on the eastern side of the road about 150 yards south of the cross-roads. Lowest Downtonian Beds and Upper Ludlow on the north are faulted against Upper Ludlow rocks on the south. In the northern part the section is as follows :—

| | | ft. | in. |
|---|---|---|---|
| Tilestones . . . . . | seen for | 1 | 0 |
| Sandy micaceous shales . . . . . | | 1 | 6 |
| False-bedded coarse sandstone, becoming black in the lower part and crowded with well-preserved dermal studs of *Thelodus* and other fish-remains (18), also fragments of *Discina* . . | | 1 | 6 |
| Well-marked junction. | | | |
| *Chonetes* Beds.—Fossiliferous mudstones . . . | seen for | 3 | 0 |

Three-quarters of a mile south of the last section, about 25 yards east of the bend in the road north of Lower Wolton, a very interesting and important section is seen in the northern bank of the lane :—

| | | ft. | in. |
|---|---|---|---|
| Tilestones, very well bedded . . . . . | seen for | 1 | 0 |
| Tilestones, purplish and more irregular than the above . . | | 1 | 0 |
| Ludlow Bone-bed—a very false-bedded coarse purplish grit, full of fragments of bone and pebbles (especially flat pebbles of shale) up to one inch in length. When unweathered the rock is pale coloured and calcareous, showing large glistening cleavage surfaces of calcite. In the lower part are boulders of limestone (? Aymestry Limestone) up to 8 inches in diameter . | | 1 | 6 |
| Sharp junction. | | | |
| *Chonetes* Beds.—Fossiliferous shales . . . . | seen for | 3 | 0 |

The fossils of the Bone-bed include 4a (very abundant), 7, 16, 33, 39, 40, 45.

(vi) Between Lyne Down and Gamage Ford (Here. XLVII, N.W.). On the western side of the lane, nearly opposite the cottage, may still be seen the old section described by Phillips [1] with the thick representative of the Ludlow Bone-bed. The section is 100 yards north of the bridge over a stream :—

| | | ft. | in. |
|---|---|---|---|
| Very sandy micaceous shales . . . . . | seen for | 1 | 0 |
| Fine-grained tilestones . . . . . | | | 9 |
| Sandy micaceous shales . . . . . | | 2 | 6 |
| Conglomerate of bone-fragments, green shale pebbles, and pebbles up to 3 inches long crowded with *Chonetes*. The bed is somewhat irregular; there are bands of shale; the upper part is hard, but the lower part, probably calcareous in depth, is in the state of brown powder. This conglomerate is the representative of the Ludlow Bone-bed . . . . . | | | 9 |
| Sharp junction. | | | |
| *Chonetes* Beds.—Well-bedded shales and flagstones (of Upper *Chonetes* Beds type). Fossils include 33, 34, 39, etc. . . . | seen | 2 | 0 |

The fossils of the Bone-bed include 7, 8, 16, 23, 33, 39, 45 ?.

[1] Phillips, op. cit., p. 178.

A very similar section can be seen a few hundred yards to the south-west in the southern bank of the road opposite the turning which leads up to Welch Court. The Bone-bed yields 7, 39, etc.

(*c*) *May Hill Inlier.*

The writer has not personally visited this inlier, which forms the natural extension to the south-east of the Woolhope Inlier. It has been studied recently by Mr. C. I. Gardiner,[1] who states that he has not seen the Ludlow Bone-bed to the north, but that it is over a foot thick in the south at Blaisdon. Judging by a specimen which he kindly furnished, it appears to be a conglomeratic bed as at Gamage Ford and Rushall. There are numerous tiny phosphatized pebbles about ½ inch long. The Downton Sandstones are very thick to the north of the inlier, and are said to reach 200 feet in the old quarries on Gorstley Common, but are much thinner in the south.

Taking the Woolhope and May Hill districts as a whole, one may say that the Ludlow Bone-bed of normal character has only been found in the extreme north-east at Hagley. Round the northern part of the area its place is taken by a "claystone conglomerate" with scattered fish-remains. To the south it is definitely conglomeratic—a "Bone-bed Conglomerate" with an abundance of phosphatized pebbles and other pebbles up to several inches in diameter. Everywhere the base of the Downtonian is sharply marked, and there is a distinct "ravinement" at the base. The highest Ludlovian rocks in some cases appear to be of Upper *Chonetes* type, in others of Lower *Chonetes* type, but the Upper Ludlovian rocks are not readily separable into *Rhynchonella* and *Chonetes* Beds, owing to the extended downward range of the zone-fossil of the latter. The presence of pebbles of ? Aymestry Limestone in the Bone-bed would seem to indicate a local unconformity of greater magnitude than to the north. The gradual passage of the Bone-bed into a conglomerate southwards is of great interest in view of the marked unconformity which comes on in that direction. Almost throughout the district the abundance of *Thelodus* in the Lower Downtonian—not only in the Bone-bed but also in the succeeding sandstones—is remarkable. The fish must have simply swarmed in the shallow waters of the period, and one is tempted to speculate whether the bands of broken *Lingulæ*—so frequent in the *Platyschisma* Shales—do not indicate their feeding-grounds.

7. *The Tortworth and Mendip Inliers.*

To the south of the May Hill district is the section of Purton Passage on the southern bank of the River Severn, and at the northern end of the Tortworth Inlier. The Upper Ludlow is here

[1] Gardiner, "The Silurian Rocks of May Hill": *Proc. Cotteswold Nat. F.C.*, vol. xx, pt. iii, 1920, pp. 185–222.

much attenuated and several bone-beds—in which the preservation of the fish-remains is said to be exceptionally good—are stated to occur, presumably in beds corresponding to the Downton Sandstone. Unfortunately these beds are usually covered by river mud, and the writer has not had an opportunity of studying them. The southern end of the Tortworth Inlier has been investigated by Professor Reynolds.[1] The presence of Ludlow Beds is doubtful, and he is "of opinion that the variability in the thickness of the Old Red Sandstone and the probable absence of the greater part, or even locally of the whole, of the Ludlow Series are to be attributed to upheaval and erosion of the area in late Silurian and early Devonian times" (p. 535). Phillips also clearly recognized the existence of an unconformity.[2]

Still further south is the Silurian Inlier of the Eastern Mendips, also studied by Professor Reynolds.[3] He concludes that "Ludlow Beds, if present at all, must be very thin. It is probable that the highest Silurians and the lowest Old Red Sandstone are both missing, and, as far as the scanty evidence available from dips goes, there is a considerable discordance between the Wenlock and the Old Red Sandstone" (1911, p. 80).

### 8. *The Usk Inlier.*

As recent investigation has shown,[4] a normal junction between the Devonian and Silurian rocks of the Usk Inlier is not readily seen. Except on the western side, the junction is usually faulted.[5] In the neighbourhood of Llandegveth (Monmouthshire, XXIV, S.W.) the *Chonetes* Beds have the usual characters and fauna, but with the addition of bands of "rottenstone"—full of a large species of *Holopella* and various lamellibranchs. The actual junction was not seen, but the Devonian Basal Sandstone of a somewhat higher horizon is exposed in an old quarry about 600 yards south-west of Llandegveth Church. It was in this quarry that the Geological Survey found *Eukeraspis*, and hence deduced the "Lower Old Red Sandstone" age of the "Basal Beds" in the eastern part at least of the South Wales Coalfield.[6] The writer detected numerous fragments of *Onchus* (spines) and *? Eukeraspis*. The latter is essentially a Downtonian genus, and usually characterizes

[1] Reed & Reynolds, "On the Fossiliferous Silurian Rocks of the Southern Half of the Tortworth Inlier": *Q.J.G.S.*, vol. lxiv, 1908, pp. 512–43.

[2] Op. cit., p. 197.

[3] Reynolds, "A Silurian Inlier in the Eastern Mendips": *Q.J.G.S.*, vol. lxiii, 1907, pp. 217–38; "Further work on the Silurian Rocks of the Eastern Mendips": *Proc. Bristol Nat. Soc.*, ser. iv, vol. iii, 1912, issued for 1911, pp. 76–82.

[4] Gardiner, *Proc. Cotteswold Nat. F.C.*, vol. xix, 1916, p. 129; Strahan and others, "Geology of the South Wales Coalfield: Part I. The Country around Newport, Mon., 1899, 2nd ed., 1909; Part II. The Country around Abergavenny, 1909": *Mem. Geol. Surv.*

[5] Geological Survey Maps, 1 inch, N.S., Sheets 232 and 249.

[6] "Country around Newport": op. cit., pp. 15, 18.

the *lower* part of that series. The " Basal Beds " of the " Old Red Sandstone " of the eastern part of the South Wales Coalfield are thus Downtonian in age. The extended downward range of *Chonetes striatella* again makes it difficult to subdivide the Upper Ludlovian, but a full sequence appears to be present, and the unconformity at the base of the Devonian, if existing, can only be slight.

### 9. *Cardiff.*

The Silurian Inlier of Cardiff constitutes part of the core of the Cardiff-Cowbridge Anticline, and the Silurian rocks are found in several patches in the Palæozoic floor on which the Triassic deposits of Cardiff itself rest. The exposed Silurian rocks occupy a small area to the north-east of Cardiff, and have been studied by Sollas.[1] The highest beds are crowded with fossils (33, 34, 36, etc.), and are succeeded rapidly by deep red or purplish flaggy micaceous sandstones of Old Red Sandstone type. The junction is rarely visible and the iron-staining of the highest Silurian beds tends to obscure the demarcation. Sollas states that " just above the highest Ludlow and below the Old Red Sandstone a brownish grit, speckled with grey felspathic particles, occurs. It abounds in fragments of fish-bones, which, however, with the single exception of *Onchus tenuistriatus*, are too obscure to be even generically identifiable ". In studying the cores from a boring at Cardiff, Dr. F. J. North selected a well-marked band of sandstone as the base of the " Old Red Sandstone ". On re-examination this band of sandstone was found to be full of fish-remains, but the writer was unable to identify any of the fragments. There can be little doubt, however, that this band is the true local base of the Devonian and equivalent to the fish-band mentioned by Sollas. There is no apparent unconformity between the Devonian and Silurian in the Cardiff district, but the Silurian rocks " represent a rather sandy and shallow-water facies of the Shropshire type, and they indicate that the shore-line could not have been far distant. From the known distribution of the Silurian Rocks of Wales it is clear that this shore-line must have been to the south, though evidence as to its exact position is wanting ".[2]

### 10. *Kington.*

There is little to add to the original account of this district, given by R. W. Banks.[3] The succession may be tabulated thus :—

Temeside Shales—rubbly, olive-green shales with a roughly sphaeroidal structure and with numerous calcareous nodules (cornstones).

Downton Sandstones—massive yellowish or grey sandstones, sometimes

[1] Sollas, " On the Silurian District of Rhymney and Pen-y-lan, Cardiff " : *Q.J.G.S.*, vol. xxxv, 1879, p. 475.

[2] Cox, " The Geology of the Cardiff District " : *Proc. Geol. Assoc.*, vol. xxxi, 1920, p. 51.

[3] Banks, " On the Tilestones, or Downton Sandstones, in the neighbourhood of Kington, and their contents " : *Q.J.G.S.*, vol. xii, 1856, p. 93.

false-bedded, passing down into thinly bedded sandstones, sometimes micaceous (tilestones).
Bone-bed and *Platyschisma* Band (2–3 inches).
*Chonetes* Beds—greenish, thinly bedded shales.

The junction may still be seen in Bradnor Lane (N.W. of Kington), which leads up from Newton to Bradnor Hill (Here. XVII, N.E.). The lowest beds seen are typical Upper *Chonetes* Beds (with layers crowded with 33, 34, 35, and 39). The dip of the beds is slightly less than the slope of the lane, so that individual beds may be followed for some distance. About 50 to 100 yards up the lane (about the 700 ft. contour line) a somewhat conspicuous 6- to 9-inch band of rather harder rock is seen on the western side. The lower part of it is crowded with fossils and constitutes a "rottenstone". Two feet above this bed is a band 2–3 inches thick, consisting largely of *Platyschisma helicites* and *Modiolopsis complanata*, but constituting a veritable Bone-bed in the lower part, being crowded with *Thelodus parvidens*. Above the Bone-bed the strata quickly become more sandy and *Lingula minima* is very common. Although the actual junction is not visible, a similar succession can be made out along the sides of the deep gully immediately west of the "Quarry" on the eastern slopes of Bradnor Hill. There are also numerous quarries in the massive sandstone of the higher part of the Downton Sandstone. They have become celebrated from the numerous and remarkable fish and Eurypterid remains which they have yielded. The quarries of Bradnor Hill and Ivy Chimney are especially noteworthy. Conglomeratic beds with pebbles of red and white quartz also occur in the sandstones, and some of the pebbles, according to Banks, suggest derivation from the Pre-Cambrian complex of Old Radnor to the west. In some localities (old quarries in Park Wood, Here. XVII, N.W.) some thin layers consisting almost entirely of *Thelodus* may be detected. The junction between the sandstones and the overlying Temeside Shales may be seen in an old quarry in Park Wood (just north of the "k"), west of Kington. The writer is much indebted to Mr. W. H. Banks, of Hergest Croft, Kington, for his kind assistance in this district. Mr. Banks has a magnificent collection of local fossils, and one of great importance in the study of Downtonian faunas. Fossils collected or contained in this collection include:—

Bone-bed: 1, 4*a* (abundant), 7 or 8, 32, 34, 39, 40, and long black spinose bodies.
Downton Sandstones: 4*a*, 18, 24, 25, 27, 29, 44, 45, 47*a*, 51, and fucoids.

The concluding remarks of Banks' paper are of considerable interest:—

Adopting the test made use of by M. Alcide d'Orbigny in order to ascertain whether these beds belong to the Old Red Sandstone, as was originally considered by Sir R. Murchison, or to the Ludlow Rocks, the absence of the mollusca of the Ludlow Rocks and the presence of Fishes and Crustaceans, which have never been found in the Ludlow Rock, and the greater development of *Pterygotus*, which occurs in Scotland in the middle beds of the Old Red Sandstone, lead to the conclusion that these Downton, or Tilestone

beds, should be considered as separate from the beds in which the Molluscs of the Upper Ludlow Rock occur, and be classed as the bottom beds of the Old Red Sandstone. Doubtful as it is whether the buckler-like fossil remains above referred to belonged to Fishes or to Crustaceans, it is certain that they are closely allied to *Cephalaspis Lloydii* and *C. Lewisii*. This fact will probably be sufficient to remove all doubt that the beds in which they occur form part of the Old Red Sandstone.

### 11. *Central Wales.*

From near Builth, south-westward to Llandilo, the higher Silurian and Lower Devonian (Old Red Sandstone) rocks are steeply inclined—forming as they do the south-eastern limb of the Towy Anticline. In the northern part of this area the Old Red Sandstone gives rise to a great stretch of weird and desolate moorland—mostly over 1,000 feet above sea-level—known as Mynydd Eppynt. The hard beds at or near the base of the Old Red Sandstone form a boundary ridge—curiously regular in height—which separates this region from the relatively fertile rocks of the Vale of Towy. It is only where this ridge has been cut through by some powerful stream that sections showing the junction of the Silurian and Devonian can be seen. Very little is known concerning this region, and it is particularly desirable that a careful study be made of the district south of Builth and between Kington and Llanstephan. It is in this area that the passage from the clear sequence at Kington to the imperfectly understood succession in Central Wales will be seen. The author's work has been restricted to a study of the more important stream sections and must be regarded as incomplete. The fossils from these localities are not included in the general lists.

(*a*) *South-east of Llangammarch and Llanwrtyd.* (Ordnance Survey, 1 inch, Large Sheet Series, sheets 79 and 80.) There are indications of the presence of micaceous sandstones (tilestones) and reddish conglomeratic bands like the Trichrûg Beds of the Llandilo district.

(*b*) *Valley of the Afon Gwydderig, between Llandovery and Trecastle.* The beds are here dipping at about 50° to 60° to the south-east. The succession near the fifteenth milestone from Brecon is as follows :—

? Age.—Red marls with scattered cornstones and bands of purplish sandstone and hard marl.

? Downtonian.—Very hard blue-grey micaceous sandstone, massive, almost a quartzite, with lenticular bands of fossils. The calcite of the latter weathers out, leaving the fossils as moulds only.

Ludlovian.—Soft mudstones and shales, thinly bedded, with *Rhynchonella, Orthis*, etc.

Although it is not seen, the junction between the sandstone and the underlying mudstone would appear to be sharp and well defined. The Ludlovian shales are seen in the corner of a garden on the bank immediately above the 15th milestone, and they cannot be more than a few yards below the hard sandstones which are quarried

extensively on either side of the road near by. The fossiliferous bands yielded 34, 45, 47, 49, 51, 52 ?, 54, 57 spp. The fossils suggest that this hard sandstone is the lateral equivalent of the lower part of the Downtonian of Shropshire. The overlying red beds are seen opposite the cottages 150 yards east of the milestone.

(*c*) *Valley of the Afon Sawdde, south-east of Llangadock.* A magnificent section is visible in the gorge of this little stream. The water rushes through a comparatively narrow channel, with walls of rock 20 or 30 feet high on either side.[1] The beds are very steeply inclined, and strike directly across the stream. Certain of the beds are quarried on the northern side of the river, and additional facilities are afforded for a study of the beds. The following section can be made out :—

Red and green marls with many hard beds—sandstones, cornstones, etc. Marls predominate towards the top. Seen between the mill and the bridge at Pont-ar-llechan. Below are greenish, occasionally mottled, sandstones, very micaceous and irregularly bedded in places, with bands of red or red and green mottled marl. Seen for about 250 yards below the bridge. Probably equivalent to the higher part of the Trichrûg Beds and " Green Beds " at the base of the Old Red Sandstone in the Llandilo district.

Purplish sandstone with a few thin shale bands and thin beds of quartz conglomerate in the lower part, passing upwards into hard, reddish quartzite. The latter becomes mottled (red and green) in the higher part and just above some conspicuous rocks in the banks of the stream is the lowest bed of red marl, taken as the base of the succeeding division. Thickness 150 feet. Probably equivalent to the *Grammysia* and Trichrûg Beds of Llandilo.

Ludlovian—beds of soft shale, giving rise to eroded bays on either side of the stream (8 feet) passing down into shales with bands of hard purplish sandstone and then into normal Silurian shales. Examined for 100 feet.

A quarry in the lowest beds mentioned above yielded *Chonetes striatella, Rhynchonella nucula, Atrypa reticularis, Acaste downingiæ, Pterinaea*, and various lamellibranchs, as well as *Orthis* spp., *Spirifer elevata ?, Wilsonia wilsoni ?, Bellerophon trilobatus*, and *Holopella* sp. There is another small quarry in the very base of the " *Grammysia*-Trichrûg Beds ", which shows the sharp junction with the underlying soft shales. The pebbly layers in this quarry are fossiliferous, and yielded 47, 51, 54, 55, *Grammysia* and *Rhynchonella nucula*. Certain beds of purplish sandstone (exactly like the *Grammysia* Beds of Llandilo) are very rich in *Grammysia*, also 33 and 34. The fauna of the *Grammysia*-Trichrûg Beds right from the base is strongly suggestive of the fauna of the *Platyschisma* Shales, and in the absence of fish-remains the base of the Devonian is provisionally placed here. The presence of *Atrypa* in the underlying shales suggests an horizon rather low in

[1] Measurements of the whole section have been given by H. T. De la Beche (" On the formation of the Rocks of South Wales and South-Western England " : *Mem. Geol. Surv.*, vol. i, 1846, p. 23). In the absence of any lists of fossils it is difficult to interpret his section, but apparently the beds just below the bridge are those indicated as " fossiliferous ".

the Upper Ludlovian ; possibly there is a considerable unconformity between the *Grammysia* Beds and the Upper Ludlovian.

(*d*) *Llandilo District.* The region to the south of Llandilo has been described in detail by the Geological Survey.[1] They state that the Silurian rocks, where best developed in the neighbourhood lying east of Llandilo, present the following subdivisions in descending order :—

| | Feet |
|---|---|
| *Tilestones.*—Yellow, highly micaceous sandstones and pebbly grits, very fossiliferous . . . . . about | 150 |
| *Trichrûg Beds.*—Red grits, sandstones, and sandy marls, mostly pebbly, passing down into yellow grits . . . . . | 600 |
| *Grammysia Bed.*—Dark purple-grey flaggy sandstones characterized by *Grammysia* . . . . . | 180 |
| Greenish-buff mudstones with thin harder seams . about 600 feet<br>*Lletty Grit.*—Yellow sandstone . . . . . 200 feet<br>Greenish-grey mudstones . . . . at least 1,200 feet | 2,000 |

All these beds are classed by the Survey as Wenlock-Ludlow. The three higher divisions thin westwards and die out successively, the oldest or lowest first. In the east these beds pass up directly into the red marls of the Old Red Sandstone, but to the south-west of Llandilo where they have thinned out entirely, a thickness of some 450 feet of "Green Beds" suddenly sets in at the base of the Old Red Sandstone. Without asserting that the Survey's interpretation is incorrect, the writer would point out that there are strong grounds for believing that the beds from the *Grammysia* Bed to the Tilestones inclusive pass laterally into the "Green Beds", and that both series are probably Downtonian in age. The reasons for considering that such is the case are briefly as follows :—

1. The *Grammysia* Bed, Trichrûg Beds, and Tilestones *gradually* become less fossiliferous when traced westwards and the Green Beds still further west are unfossiliferous.
2. In the east the former beds behave as basement beds to the Old Red Sandstone and it is curious that just where this fossiliferous type of basement bed dies out, the unfossiliferous type (Green Beds) should suddenly appear—450 feet thick.
3. The Old Red Sandstone (of the Survey) is strongly unconformable on underlying rocks. Where its base is formed by the Green Beds, the lower limit is well marked and the transgression is obvious. But where it rests on Tilestones there is nowhere a well-defined base but a gradual passage from one to the other. The base of the *Grammysia* Bed, on the other hand, is sharp and clearly defined.
4. The lower part of the Tilestones often consists of greenish sandstone indistinguishable from the sandstone of the Green Beds, whilst there are beds of typical tilestone intercalated in the latter.

For details of the beds and their fossils reference should be made to the Survey's memoir, but the following details may be noted in the present connexion :—

[1] Strahan, Cantrill, Dixon, & Thomas, "The Geology of the South Wales Coalfield. Part VII. The Country around Ammonford (Sheet 230)" : *Mem. Geol. Surv.*, 1907.

*Grammysia* Bed: Fossils include various fossils common in Downtonian rocks of Shropshire (34, 36, 51, 54, 57) with the addition of others, such as *Grammysia* sp., various lamellibranchs, and a trilobite. A band of "rottenstone" in a quarry south-east of Llwyn-bedw (at the spot marked by the dip arrow of 104° on the Survey map) yielded in addition 33, 54 spp., 55, and fragments of ? *Homalonotus*.

Trichrûg Beds: The pebbly beds are conspicuous and compare closely with the beds at the base of the Downtonian (?) in the Afon Sawdde section.

Tilestones: These beds also have lenticular bands of "rottenstone" and have a fauna very similar to that of the *Grammysia* Bed. It includes 51 (large and abundant), 54, 55, and various lamellibranchs. Brachiopods have become scarce.

The affinity of the faunas of these beds is undoubtedly with the Downtonian, but in the absence of fish-remains their age cannot be regarded as certain.

### 12. *Pembrokeshire and South Wales.*

In Marloes Bay the Silurian rocks seem to pass up gradually into the Old Red Sandstone, and it is difficult to draw any line between them. This and other sections in Pembrokeshire have been fully described in the publications of the Geological Survey.[1] The Green Basal Beds of the Old Red Sandstone seem to maintain their character throughout Carmarthenshire and to pass laterally into Red Marls in Pembrokeshire.[2]

In Gower and elsewhere in South Wales there is a strong unconformity at the base of the Old Red Sandstone, which seems to prove amply the existence in Lower Devonian times of a ridge between the Welsh area of deposition and the sea which covered Devon and Cornwall.

## V. Palæontology of the Downtonian of the Welsh Borderland.

The fauna of the Downtonian rocks of the Welsh Borderland falls into three groups.

(1) Upper Ludlovian marine species which were living in the Upper Ludlow seas at the time of the change of conditions indicated by the Ludlow Bone-bed. Many of these species struggled to live on under the new conditions and are fairly abundant in the lower part of the Downtonian (Downton Sandstone), but gradually they die out and disappear. The most important are:—

*Chonetes striatella*, "*Rhynchonella nucula* (small form)" (see after), *Orthis* spp., *Discina* spp., and certain lamellibranchs.

Where the change was more gradual and deeper water conditions persisted into the early Downtonian, one gets the fauna of the

[1] *The Geology of the South Wales Coalfield*: Part X. "The Country around Carmarthen," 1909; Part XI. "The Country around Haverfordwest," 1914; Part XII. "The Country around Milford," 1916.

[2] The presence of *Pteraspis* in the red marls indicates the presence of Dittonian rocks, but these remains have not been found in the basal beds. See *Mem. Geol. Surv.*, Haverfordwest, p. 113, etc.; Carmarthen, p. 63; compare Abergavenny, pp. 16–17; Newport, 2nd ed., pp. 17–18.

*Platyschisma* Shales where still other Ludlovian forms persisted, including :—

*Orthoceras* spp., *Pterinæa*, and other lamellibranchs.

(2) Certain forms, presumably shallow water marine or brackish water species, which flourished greatly during the early part of the Downtonian, but which died out as conditions continued to change and became unfavourable. They disappear later than the members of the first group.

**Platyschisma helicites*, *Holopella* spp., **Bellerophon trilobatus*, **Modiolopsis complanata*, **Lingula minima*, **Lingula cornea*, *Eurypterus* spp., *Pterygotus* spp., *Beyrichia kloedani*, *Leperditia* sp.

Those marked with an asterisk may be regarded as especially characteristic of the lower part of the Downtonian.

(3) Numerous genera and species which appear for the first time in the Ludlow Bone-bed, and which persist during the Downtonian, or are phylogenetically connected with forms occurring in higher beds. This group includes practically all the fish-remains.

*Thelodus parvidens*, *Thelodus* spp., *Onchus murchisoni*, *Onchus tenuistriatus*, *Eukeraspis pustulifera*, *Cyathaspis banksii*.

In slightly higher beds the following become common :—

*Auchenaspis salteri*, *Ischnacanthus kingi*, *Didymaspis grindrodi*, *Tolypaspis* spp., *Oniscolepis* sp., *Cephalaspis murchisoni*.

It is this incoming fauna of new forms which persists and is the forerunner of all the fish-faunas of the Devonian, which must determine the age of the deposits. As Mr. Wickham King has pointed out, of the thirteen genera of fish which occur throughout the Downtonian of the Midlands, no less than seven occur also in the marine Lower Devonian of Britain or America.[1]

One may well ask where are the forerunners of the fish which appear in such enormous numbers and so suddenly in the Ludlow Bone-bed. In this connexion it is of interest to note that the Ludlow Bone-bed is largely made up of the tiny isolated stud-like dermal tubercles of *Thelodus*. As the Scottish specimens studied by Traquair have shown, these plates were arranged in a " leathery " skin, traces of which remain only when conditions for preservation are exceptionally favourable.[2] Under changing conditions, such as are indicated in the early part of the Downtonian, evolution is believed to be rapid. A short distance above the Ludlow Bone-bed one finds fish in which the stud-like plates have become more numerous and closer together and in which the leathery skin has become replaced by a bony layer (*Oniscolepis*, *Lophosteus*). Later the studs coalesced (*Tolypaspis*), and in the higher parts of the Downtonian the prevalent forms are those in which there is a solid bony exoskeleton ornamented by fine striæ which represent

[1] *Abs. Proc. Geol. Soc.*, No. 1075, 19th November, 1921, p. 7.

[2] Traquair, " Report on the Fossil Fishes collected by the Geological Survey of Scotland in the Silurian Rocks of the South of Scotland " : *Trans. Roy. Soc. Edin.*, vol. xxxix, 1899, pp. 827–64.

the fused studs (*Cyathaspis*, the forerunner of the Dittonian *Pteraspis*).[1] Looking now to the ancestors of the fish whose remains are found so abundantly in the Ludlow Bone-bed, what is more natural than to suppose that they were forms with a leathery skin, as yet unprotected by any hard plates or studs, and hence have left no trace ?

*Fossil Lists of the Lower Downtonian Strata.*

The following fossil-lists cannot, unfortunately, be regarded as complete. Much work remains to be done on the minute fish-remains; the lamellibranchs and gastropods of the Silurian and Lower Devonian are but little known, and the Brachiopods are worthy of critical re-examination in the light of recent work on the Continent.

(1) *Ludlow Bone-bed.* It is curious that no recent systematic attempt seems to have been made in this country to study the contents of this famous bed. Some short accounts of its fossils have been published,[2] and a detailed study of its fish-remains has been published in Russia in the German language.[3]

| *Authority for the Record.* | *Serial Number.* | *Species.* | *Localities.* |
|---|---|---|---|
| R, S . . | 1 | *Thelodus parvidens* Ag. . . | LM, S, L, M, W, K. |
| T, S . . | 2 | *Thelodus scoticus* Traquair (?) . | L. |
| R . . | 3 | *Thelodus glaber* Pander . . | L. |
| R . . | 4 | *Thelodus volborthi* Rohon . . | L. |
| S . . | 4*a* | *Thelodus* spp. . . . . | S, L, M, W, K. |
| R . . | 5 | *Thelodus* [*Coelolepis*] *lævis* Pander | L. |
| R . . | 6 | *Thelodus* [*Coelolepis*] *schmidti* Pander . . . . . | L. |
| R, ES, S, K | 7 | *Onchus murchisoni* Ag. . . | LM, S, L, M, W, K (?). |
| R, ES, S, K | 8 | *Onchus tenuistriatus* Ag. . . | LM (?), S, L, M (?), W (?), K (?). |
| R . . | 9 | *Acanthodes* sp. . . . . | L. |
| R . . | 10 | *Prionocanthus dubius* (?) . . | L. |
| R . . | 11 | *Prionognathus brandtii* (?) . . | L. |
| ES (?), S (?) | 12 | *Cephalaspis murchisoni* Egerton . | L. |
| S (?) . . | 13 | *Cephalaspis lightbodii* . . . | |
| R, S (?) . | 14 | *Tolypaspis undulata* Pander . | L. |
| R . . | 15 | *Oniscolepis dentata* Pander . . | L. |
| S . . | 16 | *Eukeraspis pustulifera* Ag. . . | W. |
| S, Woodw. . | 17 | *Cyathaspis* sp. . . . . | L, W. |

[1] Cf. Smith Woodward, "Notes on the Geology and Fossils of the Ludlow District": *Proc. Geol. Assoc.*, vol. xviii, 1904, pp. 438–9. The truth of these statements is still more apparent from the recent work of Mr. King. It is true that the more advanced forms, such as *Cyathaspis*, do occur even in the Ludlow Bone-bed, but they are relatively scarce.

[2] Hinde, "The Bone-bed in the Upper Ludlow Formation": *Proc. Geol. Assoc.*, vol. xviii, 1903–4, p. 443; Harley, "The Ludlow Bone-bed and its Crustacean remains": *Q.J.G.S.*, vol. xvii, 1861, pp. 542–52, pl. xiii; the supposed Astacoderma described in this paper are in reality fragments of other organisms and are not included in the present lists.

[3] Rohon, "Die obersilurischen Fische von Oesel": *Mém. Acad. Sci. St. Petersbourg*, ser. VII, vol. xli, No. 5, 1893.

| *Authority for the Record.* | *Serial Number.* | *Species.* | *Localities.* |
|---|---|---|---|
| S (?) | 19 | *Birkenia* sp. | W. |
| S, K | 23 | *Ischnacanthus* [*Plectrodus*] *mirabilis* Ag., including *Onychodus*. | L. |
| ES | 26 | *Eurypterus* sp. | L. |
| ES | 27 | *Pterygotus banksii* Salter | L. |
| ES | 28 | *Pterygotus problematicus* Salter | L. |
| ES | 30 | *Beyrichia* spp. | L. |
| ES | 31 | *Leperditia* spp. | L. |
| S | 32 | *Ceratiocaris* sp. | L (?), K. |
| ES, S. | 33 | *Chonetes striatella* Dalman | L, M, W. |
| ES, S. | 34 | "*Rhynchonella nucula* (small form)" (probably *Retzia bouchardi* Davidson) | L, K. |
| ES, S. | 36 | *Orthis lunata* J. de C. Sow. | L. |
| ES, S. | 37 | *Orthis* cf. *canaliculata* Lindstrom | L. |
| S | 39 | *Orthis* spp. | W, K. |
| ES, S. | 40 | *Discina* [*Orbiculoidea*] spp. (especially *D. rugata* J. de C. Sow.) | L, M, W, K. |
| ES | 41 | *Discina* [*Orbiculoidea*] *striata* J. de C. Sow. | L. |
| ES | 43 | *Lingula lewisii* J. de C. Sow | L. |
| ES | 44 | *Lingula minima* J. de C. Sow. | LM (?), L. |
| S | 45 | *Lingula cornea* J. de C. Sow. | M, W. |
| ES, S. | 46 | *Orthonota amygdalina* J. de C. Sow. | L. |
| S | 51 | *Platyschisma* (*Pycnomphalus*) *helicites* J. de C. Sow. | L. |
| ES, S. | 54 | *Holopella* spp. | L. |
| S | 55 | *Bellerophon trilobatus* J. de C. Sow. | LM. |
| S, Hinde | 58 | *Serpulites longissimus* Murch. | L, W. |
| S, Hinde | 60 | *Pachytheca spherica* Hooker. | L. |
| | | (2) *Platyschisma Shales.* | |
| ES, S. | 1 | *Thelodus parvidens* Ag. | C, L. |
| S | 4*a* | *Thelodus* spp. | C. |
| ES, S. | 7 | *Onchus murchisoni* Ag. | C, L. |
| ES, S. | 8 | *Onchus tenuistriatus* Ag. | C, L. |
| S | 17 | *Cyathaspis* sp. | C. |
| ES | 27 | *Pterygotus banksii* Salter | L. |
| ES, S. | 28 | *Pterygotus problematicus* Ag. | C, L. |
| ES, S. | 29 | *Beyrichia kloedani* McCoy | C, L. |
| S | 30 | *Beyrichia* spp. | LM, C. |
| S | 33 | *Chonetes striatella* Dalman | C. |
| S | 34 | "*Rhynchonella nucula* (small form)" | C. |
| S | 35 | *Spirifer elevata* Dalman | C. |
| S | 36 | *Orthis lunata* J. de C. Sow. | C. |
| S | 37 | *Orthis* cf. *canaliculata* Lindstrom | C. |
| S | 38 | *Orthis* cf. *elegantula* | C. |
| S | 39 | *Orthis* spp. | C. |
| S | 42 | *Discina* spp., fragments | C. |
| S | 44 | *Lingula minima* J. de C. Sow. | C. |
| ES, S. | 47 | *Modiolopsis complanata* J. de C. Sow. | LM, C, L. |
| S | 48 | *Modiolopsis* sp. | C. |
| S | 49 | *Cucullæa antiqua* J. de C. Sow. | C. |
| S | 50 | *Pterinæa* sp. | C. |
| ES, S. | 51 | *Platyschisma helicites* J. de C. Sow. | LM, C, L. |
| ES | 53 | *Holopella gregaria* J. de C. Sow. | L. |

| *Authority for the Record.* | *Serial Number.* | *Species.* | *Localities.* |
|---|---|---|---|
| S | 54 | *Holopella* spp. | C. |
| S | 55 | *Bellerophon trilobatus* J. de C. Sow. | C. |
| S | 56 | *Orthoceras marloense* Phillips (?) | C. |
| S | 57 | *Orthoceras* spp. | C. |
| S | 58 | *Serpulites longissimus* Murch. | C. |
| S | 59 | *Cornulites serpularius* Schloth. | C. |
| ES, S. | 60 | *Pachytheca spherica* Hooker. | C, L. |
| | | (3) *Downton Sandstone.* | |
| S | 1 | *Thelodus parvidens* Ag. | W. |
| S (?) | 2 | *Thelodus scoticus* Traquair | W. |
| S | 4*a* | *Thelodus* spp. | W. |
| ES, S. | 7 | *Onchus murchisoni* Ag. | L, W. |
| ES, S. | 8 | *Onchus tenuistriatus* Ag. | L, W. |
| M (?), ES (?) | 12 | *Cephalaspis murchisoni* Egerton | L. |
| ES, S. | 16 | *Eukeraspis pustulifera* Ag. | LM, L, W. |
| S | 17 | *Cyathaspis* sp. | C (?), W. |
| M, S | 18 | *Cyathaspis banksii* Huxley and Salter (including *Scaphaspis truncatus*) | L, C, K. |
| ES | 20 | *Climatius* sp. | L. |
| S (?) | 21 | *Birkenia* sp. | C (?), W (?). |
| S (?) | 22 | *Ischnacanthus kingi* A. S. Woodw. | W (?). |
| S | 23 | *Ischnacanthus* [*Plectrodus*] *mirabilis* Ag. | W. |
| M, S | 24 | *Eurypterus linearis* Salter | K. |
| M, S | 25 | *Eurypterus pygmaeus* Salter | K. |
| M | 25*a* | *Eurypterus megalops* Salter | K. |
| M, S, ES | 26 | *Eurypterus* spp. | LM, C, L, W. |
| M, S | 27 | *Pterygotus banksii* Salter | K. |
| M, ES | 27*a* | *Pterygotus gigas* Salter | L, K. |
| M, ES, S | 28 | *Pterygotus problematicus* Salter | L, W. |
| M | 28*a* | "*Parka decipiens*" Flem. | L. |
| M, ES, S | 29 | *Beyrichia kloedani* McCoy | L. |
| S | 30 | *Beyrichia* spp. | LM, C. |
| S | 31 | *Leperditia* sp. | C. |
| S | 32 | *Ceratiocaris* sp. | K. |
| S | 33 | *Chonetes striatella* Dalman | C, L, W. |
| S | 34 | "*Rhynchonella nucula* (small form)" | C, W. |
| S | 37 | *Orthis* cf. *canaliculata* Lindstrom | W. |
| S | 39 | *Orthis* spp. | W. |
| S | 42 | *Discina* fragments | W. |
| ES, S. | 44 | *Lingula minima* J. de C. Sow. | LM, C, L, W, K. |
| M, S | 45 | *Lingula cornea* J. de C. Sow. | W, K. |
| S | 47 | *Modiolopsis complanata* J. de C. Sow. | C. |
| S | 47*a* | *Modiolopsis* sp. | C, K. |
| ES, S. | | Various *lamellibranchs* | L, C, W, K. |
| M, S | 51 | *Platyschisma helicites* J. de C. Sow. | C, K. |
| S | 52 | *Platyschisma gigas* (?). | C. |
| S | 54 | *Holopella* sp. | C. |
| S | 55 | *Bellerophon trilobatus* J. de C. Sow. | C. |
| S | 55*a* | *Bellerophon* sp. | C. |
| S | 58 | *Serpulites* fragments | C. |
| S | 59? | *Cornulites serpularius* Schloth (?) | W. |
| M, ES, S. | 60 | *Pachytheca spheriac* Hooker. | C, L, W. |
| S | 61 | *Psilophyton* sp. | C, W. |
| M | 62 | "Fucoids" | (?). |

Abbreviations in the above lists :—
Authorities : M = Murchison, taken from the fossil-lists of the "Passage Beds" : *Siluria*, 4th ed., 1867, pp. 508–36 ; R = Rohon, op. cit., 1893 ; T = Traquair, op. cit., 1899 ; ES = Elles & Slater, op. cit., 1906 ; S = Stamp, op. cit., 1918, and this paper ; K = W. W. King & W. J. Lewis, op. cit., 1912, 1917.
Localities : LM = Long Mountain ; C = Clun Forest ; S = South Staffordshire ; C = Clun Forest District ; L = Ludlow District and Central Shropshire ; M = Malvern and Ledbury ; W = Woolhope Inliers ; K = Kington.

The faunas of the higher Downtonian Beds are being investigated by Mr. W. Wickham King.

## VI. Comparison with Other Regions.

### 1. *Scotland.*

Downtonian rocks were discovered by the Geological Survey in a series of inliers, surrounded by Old Red Sandstone, along the northern side of the Southern Uplands.

(*a*) Lesmahagow Inlier. The grouping adopted by the Survey is as follows[1] (in the first column is the classification proposed here) :—

| | | | |
|---|---|---|---|
| Dittn. | L.O.R.S. | 3. Andesites and Tuffs. | |
| | | 2. Chocolate-coloured sandstones with *Cephalaspis lyelli*. | |
| | | 1. Conglomerate with greywacke pebbles. | |
| | | Unconformity (seen throughout Ayrshire and the Pentland Hills, but apparent conformity in Lanarkshire). | |
| | | | feet |
| Downtonian | Downtonian | 11. Chocolate-coloured sandstone | 1,200 |
| | | 10. Conglomerate with large pebbles of quartzite | 100 |
| | | 9. Green and red mudstones with a fish-band | 100 |
| | | 8. Red and yellow false-bedded sandstones | 1,300 |
| | | 7. Local conglomerate — Hagshaw Hills Anticline | |
| | Ludlow | 6. Green flaggy and sandy greywackes, etc. | 130 |
| | | 5. Blue-grey and green shales | 200 |
| | | 4. Hard blue shales and mudstones | 350 |
| | | 3. Hard grey flagstones with fish-remains | 500 |
| | | 2. Grey-blue and olive shales | 300 |
| | (?) Wenlock. | 1. Hard bands of greywacke with shale partings | 1,300 |

Bed 2 yields *Platyschisma helicites*.

Bed 3 yields a fauna which is absolutely typical of the Downtonian of the Welsh Borderland. It includes 2, 26, 30, 32, 44, 47*a*, 50, and 51. There is not a single fossil which suggests a Ludlovian age for these beds, and the same is true of beds 4 and 5.

Bed 4—the famous *Pterygotus* Beds—yield 44, 51, etc.

Beds 5 and 6 contain 47 and 51.

[1] Peach & Horne, "The Silurian Rocks of Britain : Vol. I. Scotland" : *Mem. Geol. Surv.*, 1899, pp. 568–9. It is important to note that the term Downtonian is used in the same sense in the memoir as in this paper, viz. as the beds between the Ludlovian and the Old Red Sandstone.

Bed 9 is famous for its fish-bands yielding 26, 32, 60, and the fishes *Thelodus scoticus, Lanarkia spinulosa, L. horrida, L. spinosa, Birkenia elegans, Lasanius problematicus,* and *Ateleaspis tessellata.*

Beds 10, 11, and 1 ("O.R.S."). There is practically no evidence as to the age of these beds.

Bed 2 has *Cephalaspis lyelli,* proving its Dittonian age.

The unconformity at the base of Bed 1 (O.R.S.) is a convenient line to use as the base of the Dittonian. There seems no alternative than to regard the whole of the Survey's Ludlow Beds in this inlier as Downtonian. It follows that the supposed Silurian fish are in reality of Downtonian age, and the discovery of a truly Silurian fish in Scotland has yet to be made. This conclusion is corroborated by a direct comparison of the fish-faunas of Scotland with those of England. *Thelodus* of Bed 3 compares with the abundant *Thelodus* of the Ludlow Bone-bed and Downton Sandstone, whilst one at least of the fishes of Bed 9 (*Birkenia*) has now been recorded from the Ledbury Beds or higher part of the English Downtonian.[1]

(*b*) Hagshaw Hills Anticline. The Wenlock and Ludlow Beds of the Survey here do seem to be really of Silurian age. There is nothing in the published account to suggest a Downtonian age. It is noticeable that the basal conglomerate of the Downtonian in this inlier is well developed. The Downtonian yields *Thelodus, Lanarkia, Birkenia,* and *Lasanius.*

(*c*) Pentland Hills. There seems no reason here to depart from the grouping adopted by the Survey. In the fossil-lists from the Ludlow rocks the *absence* of *Lingula minima, Platyschisma helicites* (though *P. simulans* is common), *Modiolopsis complanata,* and the comparative scarcity of Eurypterids, together with the *presence* of *Chonetes, Rhynchonella nucula,* and numerous other Silurian forms, contrast in an extraordinary way with the fossil-lists of the supposed "Ludlow" of the Lesmahagow Inlier. The overlying Downtonian is sparingly fossiliferous, but has yielded *Birkenia elegans, Ateleaspis,* and *Lasanius,* as well as *Platyschisma helicites.*

(*d*) Kincardineshire. A very interesting development of Downtonian rocks has been described from South-eastern Kincardineshire by Campbell.[2] Resting unconformably on ? Cambrian rocks, the lower beds of the supposed "Old Red Sandstone" yielded the following fossils, giving evidence of Downtonian age: 17, 26, 32, also *Dictyocaris.* The removal of these beds to the Silurian left the Old Red Sandstone with an undefined and probably undefinable base, thus illustrating once more the practical advantages of the lower limit of the Devonian now proposed.

[1] King, *Abs. Proc. Geol. Soc.,* No. 1075, 19th November, 1921, p. 7.

[2] Campbell, "The Geology of South-Eastern Kincardineshire": *Proc. Geol. Assoc.,* vol. xxiii, 1912, p. 295; *Trans. Roy. Soc. Edin.,* vol. xlviii, 1913, p. 923; GEOL. MAG., 1911, pp. 63–9.

### 2. *Devon and Cornwall.*

The relations of the lowest Devonian rocks of South Devon and Cornwall with older rocks are still uncertain.[1] The occurrence of a fish-fauna with *Pteraspis* (*Pteraspis cornubica* McCoy) and *Cephalaspis carteri* McCoy in the Dartmouth Slates suggests that the latter are synchronous with the Dittonian and Upper Gedinnian rather than with the Downtonian. The existence of beds of Upper Ludlow age has been claimed by Upfield Green and it is possible that the Downtonian is absent.[2]

### 3. *Northern France* (*Artois*).

The recent publication of the memoir on the Siluro-Devonian fauna of Liévin by Barrois, Pruvost, & Dubois renders superfluous a detailed description of the sections here.[3] The district is of paramount importance in that it shows an uninterrupted succession of marine strata from the equivalent of the Aymestry group of England to Lower Devonian rocks. After proving, from a careful study of these marine faunas, that the base of the Devonian should be drawn below the Schistes de Méricourt, which have a local sandstone, the Arkose de Bois-Bernard, at the base, the authors proceed to prove conclusively that this horizon corresponds to the Ludlow Bone-bed in England. Working from an entirely different standpoint, they have thus formed the same conclusions as the writer has done after examining the British deposits. The authors declare emphatically that "la limite inférieure du Dévonien, autant pour des raisons paléontologiques et paléogéographiques que pour respecter l'ensemble des lois de priorité, doit être placée *sous le grès de Downton* (Ludlow Bone-bed) en Angleterre, *sous les schistes de Méricourt* (arkose de Bois-Bernard) en Artois et *sous les schistes de Mondrepuits* (poudingue de Fépin) en Ardenne". A short account of the succession in Northern France has already been published in the GEOLOGICAL MAGAZINE.[4] Only the Downtonian is represented by marine beds (Schistes de Méricourt and Psammite de Liévin), the Dittonian being represented by red or green sandstones or shales (Schistes et Grès de Pernes et de Vimy). These beds are identical faunally as well as lithologically with the Dittonian, and contain *Pteraspis rostrata*, *Pteraspis crouchii*, and *Cephalaspis lyelli*.[5]

[1] Evans, "Devonian, Sedimentary Rocks": *Handb. d. Reg. Geol.*, Band iii, Abt. 1, 1916–17, pp. 126–8.

[2] *Cyathaspis* is mentioned by Symonds, *Records of the Rocks*, 1872, in connexion with Cornwall, but apparently in error.

[3] Gosselet, Barrois, Leriche, Crepin, Pruvost, & Dubois, "Description de la Faune siluro-dévonienne de Liévin": *Mém. Soc. géol. Nord.*, vol. vi (ii), 1912–22. See review in GEOL. MAG., Vol. LX, 1923, p. 92.

[4] Stamp, op. cit., 1920.

[5] Leriche, "Contribution à l'Étude des Poissons Fossiles du Nord de la France et des Régions Voisines": *Mém. Soc. géol. Nord.*, vol. v, 1906, pp. 13–39.

### 4. *Ardennes.*

Towards the end of the Silurian period the sea retreated from the region of the Ardennes and considerable earth-movements took place, accompanied naturally by denudation. When marine waters again invaded the area it was from southerly directions, and a long continued transgression from south to north ensued. This movement of water is known as the Devono-Carboniferous transgression. Thus one finds the basal deposits of this sea resting with well-marked unconformity on Cambrian, Ordovician, and Silurian rocks up to Lower Ludlow. Naturally these basal beds are older in the south than in the north.[1] The succession in the south (i.e. the southern border of the Synclinorium of Dinant) is as follows :—

| | |
|---|---|
| Gedinnien supérieur . . | Assise de St. Hubert.<br>Assise d'Oignes. |
| Gedinnien inférieur . . | Schistes de Mondrepuits.<br>Arkose de Haybes.<br>Conglomerat de Fépin. |
| | Unconformity. |
| Cambrian. | |

The Conglomerat de Fépin had always been considered as the natural base of the Devonian until Leriche studied the fauna of the Schistes de Mondrepuits (and of other Lower Gedinnian deposits) and considered that it was a fauna comparable with that of the Upper Ludlow of England.[2] Barrois, Pruvost, and Dubois have dealt in detail with this fauna and deposit, and show very clearly that Dumont's original lower limit for the Devonian System must be restored.[3] This is equally apparent when one approaches the subject from the standpoint of the English succession. Prof. Leriche, when he visited Shropshire, was doubtless misled by the views then current in this country and did not quite appreciate the remarkable faunal change at the Ludlow Bone-bed. In order to maintain his correlation, it is now necessary to *raise* the upper limit of the Silurian in England to the top of the Red Downtonian at least 1,500 feet above the highest limit adopted by Murchison and higher than any advocated by later writers.[4] Just as the fauna of the Lower Downtonian can be divided into three groups, so can that of the Lower Gedinnian (Schistes de Mondrepuits), the place of the incoming Old Red Sandstone fish-types being taken by typical Devonian marine forms, which appear for the first time.

[1] Stamp and others, "The Geology of Belgium": *Proc. Geol. Assoc.*, vol. xxxiii, 1922.

[2] Leriche, "La Faune du Gedinnien inférieur de l'Ardenne": *Mém. Mus. r. Nat. Hist. Belg.*, vol. vi, 1912, pp. 1–58.

[3] Op. cit., 1912, pp. 212-16.

[4] Leriche, "Observations sur la limite entre le Silurien et le Dévonien à propos d'un note de M. Stamp": *Bull. Soc. belge Geol.*, vol. xxxi, 1921-2, pp. 158–66; Stamp . . . "Réponse à M. Leriche": ibid. (in the press).

### 5. *Brittany.*

In Brittany,[1] as in Northern France, we have an example of an area in which marine sedimentation was continuous from the Silurian into the Devonian. The basal Devonian beds, however, consist of relatively shallower water sediments than the highest Silurian. The latter are shales with *Orthoceras* nodules, *Cardiola interrupta*, *Ceratiocaris*, etc. The former, called the Shales and Quartzites of Plougastel, have a marine though impoverished fauna, including 34 ?, 55, *Homalonotus*, etc., and presenting some affinities with that of the *Platyschisma* Shales.

In Mayenne and Sarthe, according to Oehlert,[2] it is extremely difficult to draw any line between the Silurian and the Devonian.

### 6. *Little Missenden Borehole, Buckinghamshire.*

Palæozoic rocks were reached in this borehole at a depth of about 1,200 feet, and were penetrated for a distance of 64 feet.[3] Lithologically, the rocks closely agree with the Upper Ludlovian of Shropshire, except for the presence of limestone bands so rich in fish-remains as to be termed "Bone-beds". The fauna, however, is almost exactly that of the *Platyschisma* Shales. Each of the three groups into which the fauna of the Lower Downtonian has been divided is amply represented, and the fossils include: 1,[4] 4a,[4] 7, 8, 20 ?, 29, 30, 31, 33, 34, 36, 40, 43, 46, 47 ?, 53, 54, 55, 57, 58, 59, *Tentaculites*, and fragments of trilobites. The connexion between the area in which these rocks were laid down and the Welsh and Ardennes regions must remain a matter for speculation. Two fossils not recorded elsewhere in Britain (*Orthoceras damesi* Roemer and *Beyrichia* cf. *noetlingi* Reuter) occur in the erratics of the North German Plain. In passing, one may note that the fauna of the latter, including as it does *Onchus*, suggests their derivation from a stretch of Downtonian rocks.

### 7. *Bohemia.*

In various parts of Bohemia, the Upper Ludlovian Beds (Stage E2 of Barrande) with typical Silurian trilobites (*Phacops* and *Calymene*) and brachiopods (*Leptæna rhomboidalis*, *Dayia navicula*, and *Conchidium knightii*) are succeeded conformably by the lowest Devonian (Stage F1 of Barrande). The fauna of the latter is an impoverished one; the abundant Silurian brachiopods have disappeared, and we may note the appearance of such characteristic

[1] Barrois, "Réunion extraordinaire . . . à Pinist": *Bull. Soc. géol. France*, sér. III, vol. xiv, 1886, p. 42.

[2] Oehlert, *Cong. Géol. Inter.*, viii, 1900. Livret Guide, Guide No. vi: Livret Guide de la Réunion extraordinaire de la Société géol. France dans la Mayenne et la Sarthe, 1909.

[3] Strahan & Pringle, *Sum. Prog. Geol. Surv. for* 1915, 1916, pp. 43–6.

[4] Previously unrecorded. The writer is much indebted to the officers of the Geological Survey, especially to Mr. J. Pringle, for permission to examine the cores from this boring. They are preserved in the Museum of the Survey.

Devonian fossils as *Bronteus*. Of still greater interest is the presence of such typical Downtonian fishes as *Cyathaspis* and *Ateleaspis*.

### 8. *Portugal.*

The Palæozoic rocks of Portugal fall naturally into two regions to the south and north respectively of the crystalline massif of Evora. In the southern region the oldest fossiliferous rocks are of Middle Devonian age, whilst in the north all rocks from the Cambrian to the Lower Devonian inclusive are present. The succession there is :—

Lower Devonian-Gedinnian : San Mamede Sandstone with *Cryphæus michelini*.

Highest Silurian : Quartzites and " Schistes ampeliteux " with graptolites.

Pruvost [1] has shown that the San Mamede Sandstone, which rests conformably on the underlying Silurian beds and was formerly grouped with them, has a marine fauna including *Cryphæus* and *Homalonotus* which must cause these beds to be considered as the base of the Devonian. A fauna has been described [2] from S. Felix (Laundos) from beds which Pruvost states are immediately below the horizon of the *Cryphæus* Sandstone of San Mamede. The fauna here might almost have been from the Downton Sandstone of England, being much closer allied than Priem's list would indicate. The fossils include (list revised by Pruvost and the writer): 8 ?, *Onchus* cf *arcuatus*, 23, 26, 42, 47a, 54 ?, 57. It would seem, then, that in Portugal the graptolitic Ludlovian rocks pass up conformably into rocks with a typical Downtonian fauna and also into rocks with a more purely marine Gedinnian fauna. It would be most instructive to know the exact stratigraphical relationship between the Downtonian and Gedinnian rocks, both of which are known in the neighbourhood of Laundos.

### 9. *Norway—The Kristiania District.*

This area has been described by Kiaer in his great work on the Silurian.[3] He then correlated his highest zone (9 f.) containing *Rhynchonella nucula*, *Spirifer elevata*, *Beyrichia* sp., *Leperditia norvegica*, etc., with the Temeside Shales, and considered the overlying sandstone series as the equivalent of the Lower Old Red Sandstone. Just as in England a fauna of Downtonian fishes has now been found in the sandstones above the Temeside Shales, so Kiaer has found a series of Eurypterids and Downtonian fishes in the lower part of the Great Sandstone Series.[4] The fossils include

[1] Pruvost, " Observations sur les Terrains dévoniens et carbonifères du Portugal et sur leur faune " : *Communicaçoes do Serv. Geol. Port.*, vol. x, 1914, pp. 1–21.

[2] Priem, " Sur les poissons et autres fossiles du Silurien supérieur du Portugal " : ibid., vol. viii, 1910–11, pp. 1–10, pls. i–ii.

[3] Kiaer, *Das Obersilur im Kristianiagebiete*, 1908.

[4] Kiaer, " A new Downtonian fauna in the Sandstone Series of the Kristiania area " : *Videnskapsselkapets Skrifter* I, Mat.-nat. Klasse, 1911, No. 7.

*Dictyocaris*, *Ceratiocaris*, *Eurypterus* spp.; the new Anaspid fishes *Pterolepis nitidus*, *Pharyngolepsis oblongus*, and *Rhyncholepis*; and the new Cephalaspidian fishes *Aceraspis robustus* and *Micraspis gracilis*. The fauna is undoubtedly Downtonian. It is impossible here to discuss the evidence in detail, but a study of the faunas of Kiaer's 9e–9g suggests their correlation with the Upper Ludlovian, and possibly the base of the Great Sandstone Series above is approximately on the horizon of the Ludlow Bone-bed.

10. *Gotland.*

In Gotland the highest beds form a mass of limestone of which a portion at least is characterized by an abundance of *Ascoceras*, and is probably of Devonian age.[1] The discovery of a *Cyathaspis* (near *Tolypaspis*) in the Lau Shales is very remarkable, since these beds are usually considered as equivalent to the Wenlockian.[2] This has been claimed, perhaps rightly, as the oldest known fish, but it is unfortunate that more is not known of the stratigraphy of the beds in which it was discovered. Rohon records plates of *Thelodus*, etc., from the clay at Hammarudd, near Ostergarn.

11. *Southern Sweden* (*Scania*).

The highest Silurian is here represented by the "Oved-Ramsasa Formation", which has been divided into four beds by Moberg and Gronwall.[3] Beds 1 and 2 are probably equivalent to the *Rhynchonella* and *Chonetes* Beds; Bed 4 consists of a red sandstone with *Lingula minima* and *L. cornea*. Bed 3 is closely linked to 4 lithologically, and both would seem to be Downtonian.

12. *Esthonia.*

A brief resumé of the geology of Esthonia has been given by Schmidt.[4] The higher beds of the Silurian (Stage K or Upper Oesel Zone) occupy only the southern and western parts of the Isle of Oesel. "The Stage K can as easily be correlated with the Ludlow Group of England as the Stage I with the Wenlock." Stage K is said to exhibit several facies, and certain horizons have yielded the wonderful series of fish-remains described by Pander and Rohon. The true base of the Devonian, the equivalent of the Ludlow Bone-bed in England, undoubtedly lies within the Stage K. It is interesting to note that Rohon, not doubting, of course, the Silurian age of the Ludlow Bone-bed and describing

[1] Munthe, "The sequence of Strata in Southern Gotland": *Geol. Fören. i Stockholm Förhandl.*, Bd. 32, H. 5, pp. 1397–1453, 1910; also Exc. Pamph. 19, xi, *Cong. Geol. Inter.*, 1910.

[2] Lindström, "On Remains of a *Cyathaspis* from the Silurian Strata of Gotland": *K. Vet. Akad. Handl.*, Bd. 21, 1895; see also review in GEOL. MAG., 1895, pp. 170–4.

[3] Summary by Moberg, "The Silurian of Sweden": *Sveriges Geol. Undersökning*, No. 229, 1910.

[4] Schmidt, "On the Silurian . . . of the Baltic Provinces of Russia": *Q.J.G.S.*, vol. xxxviii, 1882, pp. 514–35.

the fish-remains as an Upper Silurian fauna, terminates his memoir by remarking :—

> "Alles bisher Gesagte führt mich schliesslich zu der Aufstellung, wonach die obersilurische Fischfauna von der Insel Oesel einerseits die Vertreter der Selachier, Dipnoer und Ganoiden umfasst, andererseits aber trotz der bestehenden Unterschiede mit der devonischen und carbonischen Fischfauna genetisch verbunden ist."

The Old Red Sandstone of the Mainland rests with strongly marked discordance on beds varying in age from the Cambrian to the Wenlock, but it is not seen in contact with the highest beds or Stage K. The sandstone yields *Coccosteus*, *Asterolepis*, and *Homosteus*, and hence belongs to a high horizon in the Old Red Sandstone.

### 13. *Spitsbergen.*

A brief summary of the Devonian succession in North-western Spitsbergen, which has only become known within the last decade, has recently been given by Kiaer.[1] The beds there are of Old Red Sandstone type, and reach the enormous thickness of 9,000 metres or 30,000 feet.

| | | |
|---|---|---|
| Wijdebay Series | Greyish sandstone and grey and red shales | 2,000 m. |
| Grey Hook Series | Shales with bands of sandstone | 2,000 m. |
| Woodbay Series | Micaceous reddish sandstone and shales | 2,500 m. |
| Red Bay Series | *Pteraspis* Beds.—Red sandstones and shales<br>Ben Nevis Beds.—Massive greenish sandstone<br>Red and green sandstone with foss. bands<br>Unfossiliferous sandstone (100–200 m.)<br>Conglomerate (500–600 m.) | 2,200 m. |

Unconformity.

Caledonian schists, gneisses, and granites.

The Red Bay Series are the oldest fossiliferous beds in Spitsbergen, and have yielded more than 30 species, as well as undetermined ostracods and small lamellibranchs. The fish include such typical Downtonian Palæaspideans as *Palæaspis* and *Cyathaspis* ; Cephalaspideans such as forms allied to *Eukeraspis*, *Didymaspis*, and *Auchenaspis*. In the higher beds (especially in the cornstones of the *Pteraspis* Beds) there are also representatives of the Pteraspidæ (*Pteraspis*). Thus the fauna is a typically Downtonian one with the oncoming of Dittonian forms in the higher parts. The Woodbay Series, following quite conformably, has a typically Dittonian fauna. Palæaspideans no longer occur, Cephalaspideans and Pteraspideans are dominant, and *Coccosteus* is found. The Grey Hook Series has a molluscan fauna indicating the lower part of the Middle Devonian. The Wijdebay Series has a fish-fauna (*Clyptolepis*, *Arctolepis*, and *Psammosteus*) indicating the lower part of the Upper Devonian. Once again one sees in Spitsbergen how impossible it is to draw the limit between the Silurian and Devonian, between the Downtonian and Dittonian.

[1] Kiaer, "Spitsbergens devoniske faunaer" : *Förh.* 16 *Skand. Naturforsk.*, 1916.

It would fall somewhere in the Red Bay Series, whereas the natural stratigraphical break at the base of the Red Bay Series is on the same horizon as the natural base of the Devonian in England, France, and Belgium.

### 14. *America.*

The base here suggested for the Devonian of North-western Europe would appear to be quite convenient for the United States. The succession in New York State is as follows :—

Helderberg Group (Lower Devonian).
Manlius (*sensu lato*) { Manlius Limestone (*sensu stricto*). / Rondout Waterlime. / Cobleskill Limestone.
Salina Beds (*sensu stricto*).
Niagara Group (Wenlockian).

The Salina Beds comprise a series of gypseous and saline marls with very few fossils (*Eurypterus* in the upper part). The succeeding beds, grouped together as Manlius by Schuchert,[1] are characterized by a very special fauna of Eurypterids,[2] and " except for their singular occurrence in Colorado in the Ordovician, fish-remains have not been found in America until this stage." [3] *Palæaspis americana* is the typical form in Pennsylvania. The Manlius Limestone marks a return of more truly marine conditions. Prof. Schuchert views favourably the placing of the base of the Devonian at the horizon of the Ludlow Bone-bed, and says :—

" It now appears clear that the black limestones of Bohemia known as the Ff1 beds, and the Tentaculite Limestone or the Manlius of New York, must also go into the Lower Devonian. Just where the division line in Maryland, Pennsylvania, and New Jersey will be drawn is, however, not so clear, for here there appears to be a more or less complete transition from the Silurian (Tonoloway) into the Manlius equivalent." [4]

## VII. Probable Palæogeography of Lower Devonian Times.

The Silurian deposits of England seem to have been laid down in a trough with a trend from south-west to north-east, and of which the shore-line ran obliquely across England from the region of the Mendip Hills. The Silurian deposits under London appear to belong to a separate basin of deposition—the Brittany-Ardennes Province. In Upper Ludlovian times the trough had become nearly silted up. The Siluro-Devonian Earth-Movements, which terminated the Silurian and continued well into Devonian times,

[1] Schuchert, *American Geologist*, March, 1913, pp. 1617–18.

[2] For details see Hartnagel, " Preliminary Observations on the Cobleskill (' Coralline ') Limestone of New York " : *New York State Mus. Bull. for* 1902, 1903, p. 1109.

[3] Chamberlin and Salisbury, " Geology " : *Earth History*, vol. ii, 1906, p. 376.

[4] Schuchert, " The Boundary between the Silurian and Devonian in Shropshire and France " : *Science*, N.S., vol. lii, 8th October, 1920, p. 340.

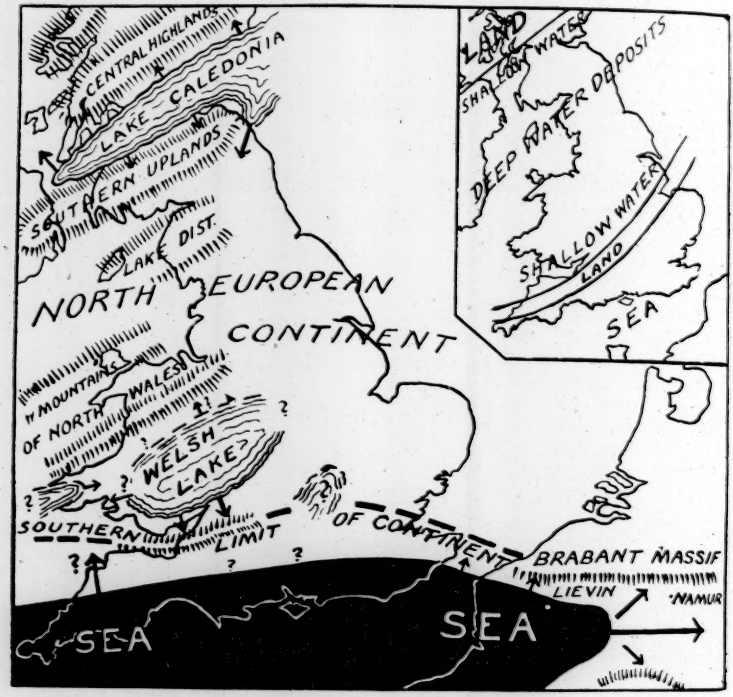


FIG. 2.—Sketch-map showing the probable geography of earliest Devonian times. An attempt has been made to indicate the mountains which were uplifted by the Siluro-Devonian folding, and the lakes which occupied the basins between the ranges. Inset is a Sketch-map of the probable geography of Silurian times, showing the sea of which the Downtonian lakes represent portions isolated by folding. The early Downtonian lakes and Gedinnian sea rapidly transgressed their first limits, in the directions shown by the arrows. Northern France and Belgium after Barrois, Pruvost, and Dubois. Despite recent statements to the contrary,[1] the writer is compelled to adhere to the idea that a ridge existed between the Downtonian Welsh Lake and the Gedinnian sea of Devon and Cornwall. The arguments for this belief are briefly as follow:—

(i) The known distribution of Valentian deposits shows that in early Silurian times a ridge ran obliquely across England from N.E. to S.W., roughly through the Mendip Hills, separating a Welsh-Scotch province from a Brittany-Kent-Ardennes province.

(ii) The variation of later Silurian deposits, notably the thinning and oncoming of shallow-water sediments when traced to the south-east from Wales (cf. Cardiff, above, page 389), shows that this ridge persisted.

(iii) The Downtonian lakes were cut off by upheaval, and the consequent isolation of portions of the late Silurian sea and the first formed Devonian mountain ranges bear a close relationship with the direction of the intra-Ordovician and intra-Silurian folds. The Silurian barrier is more likely to have been accentuated than obliterated.

[1] Evans, *Proc. Geol. Assoc.*, vol. xxxiii, 1922.

(iv) In Belgium and Northern France there is known to be a Devonian transgression northwards against a ridge thrown up by the Siluro-Devonian folding. The lithological variation of the Devonian in Devon and Cornwall is closely comparable, and at once suggests northward transgression against a ridge, which would be a direct continuation of the Belgian ridge. Structural arguments can also be adduced in support of this supposition.

(v) As this paper shows, there is evidence of a slight unconformity at the base of the Devonian in Shropshire, increasing steadily in importance southwards until in the Mendip Hills the Ludlovian is probably absent, whilst in parts of South Wales the Old Red Sandstone (exact age of basal beds uncertain) rests directly on Ordovician, Cambrian, and Pre-Cambrian. It is difficult to see how this could be unless a ridge separated the Welsh Lake from the sea of Devon. The connexion of the earliest Devonian rocks in Pembrokeshire with the rest of the Welsh area is uncertain.

The ridge from South Wales to Belgium marks the southern limit of the great North European Continent of Devonian times.

were of world-wide importance. Some of the more important effects may be noted.

1. The formation of a great North European Continent with high mountain ranges and deep troughs in which were deposited the Old Red Sandstone type of deposits.
2. The cutting off of arms of the sea in the north and the retreat of the ocean southwards.
3. The first movements were followed immediately by the commencement of a world-wide transgression, not only of the southern sea, but also of the waters of the larger basins. Thus the Gedinnian deposits are transgressive against the ridge to the north of Belgium, Northern France, and possibly also in Devonshire: the basal Downtonian deposits rest unconformably on older rocks and mark the commencement of a transgression in Wales (against the South Wales ridge), in Scotland (Kincardineshire, against the newly-formed mountains of the Central Highlands), and in Spitsbergen.

Some attempt has been made to show the possible palæogeography of Early Devonian times in Fig. 2. It would seem, then, that the Downtonian fish flourished in brackish water lagoons. Many of them became specialized for life in inland basins (*Pteraspis* of the Dittonian); others appear either to have been capable of living in the sea or to have adopted a definitely marine habitat (*Pteraspis* of Gedinnian ?). *Pteraspis* and its allies cannot be definitely taken as indicative of Old Red Sandstone conditions.

## VIII. Conclusion and Summary.

In conclusion the author would like to express his thanks to many friends—too numerous to name individually—but especially to M. A. Renier, Director of the Geological Survey of Belgium, MM. Asselberghs and Maillieux, Professor Barrois and Professor Pruvost, and Mr. W. Wickham King. For their companionship in the field the writer is indebted to Mr. S. W. Wooldridge, B.Sc., Mr. J. E. Austin, B.Sc., and Mr. H. C. Berdinner.

*Summary.*

The main thesis of this paper is to show that the Ludlow Bone-bed forms the true base of the Devonian System. This is urged on several grounds.

(a) *Priority.* It was the limit originally used by Murchison. Although subsequently altered by him, one finds if one attempts to use his later limit :—

(i) That the Old Red Sandstone was not re-defined accordingly.

(ii) That Dumont's Rhénan (Devonian) System, defined in 1845, has priority over Murchison's later definition (1848).

(iii) That the later limit adopted by Murchison does not form a true horizon and has been very differently interpreted by later writers.

(b) *Palæontology.*

(i) There is a marked faunal change at the Ludlow Bone-bed. The Bone-bed marks the first appearance of fossil fishes, and thus the Devonian marks the dawn of an age of vertebrates. There is only *one* old record of a pre-Devonian fish in the British Isles; one doubtful one in Gotland, and an anomalous one in the Ordovician of America. The Shropshire succession forms a standard of comparison for all areas of the Old Red Sandstone type of deposit.

(ii) The limit adopted after a detailed study by other writers of an uninterrupted marine series is on the same horizon. The succession at Liévin (Northern France) forms a standard for comparison of all areas of the Devonian (marine) type of deposit.

(c) *Stratigraphical.* In England the Ludlow Bone-bed marks also a change in physical conditions, more noticeable elsewhere as an unconformity. Physical breaks or unconformities on the same horizon occur in Scotland, Belgium, Brittany (slight), Norway, Sweden, and Spitsbergen.

(d) *Practical Considerations.* The Downtonian rocks, i.e. the strata from the Ludlow Bone-bed horizon upwards, form a stratigraphical and palæontological entity, incapable of broad or even of rough separation below the Dittonian. The Ludlow Bone-bed, on the other hand, forms an horizon which can be recognized and mapped all over North-Western Europe. In England there appears to be a slight faunal break between the Downtonian and Dittonian, but this is less marked elsewhere.

## Genesis of Rhombic Pyroxene in Thermal Metamorphism.

By C. E. Tilley.

RHOMBIC pyroxene as a constituent of thermally altered sediments has hitherto been recorded only from a few contact zones, and, as the conditions under which it is generated in metamorphosed sediments are of some interest, these may be examined.

The iron-bearing member—hypersthene—was first noted almost simultaneously by Ramsay (1)[1] and Brögger (2), by the first named in the contact zone of the Umptek nepheline-syenite, and by Brögger among the contact rocks of the Sölvsberg essexite. The explanation for the development of this mineral was not forthcoming from either of these occurrences, but Brögger made the tentative suggestion of addition of material from the basic magma.

[1] Numbers in parentheses refer to bibliography at end of paper.

A long period elapses before this mineral is again referred to. Erdmannsdörffer (3) describes it as a constituent of sedimentary hornfelses in the Harz in 1909, and in his detailed examination of the Kristiania contact zones, V. M. Goldschmidt (4) has recorded it from many localities. It is here that we first find an explanation of its occurrence in the ordered classificatory scheme of the hornfelses of this area set down by this investigator.

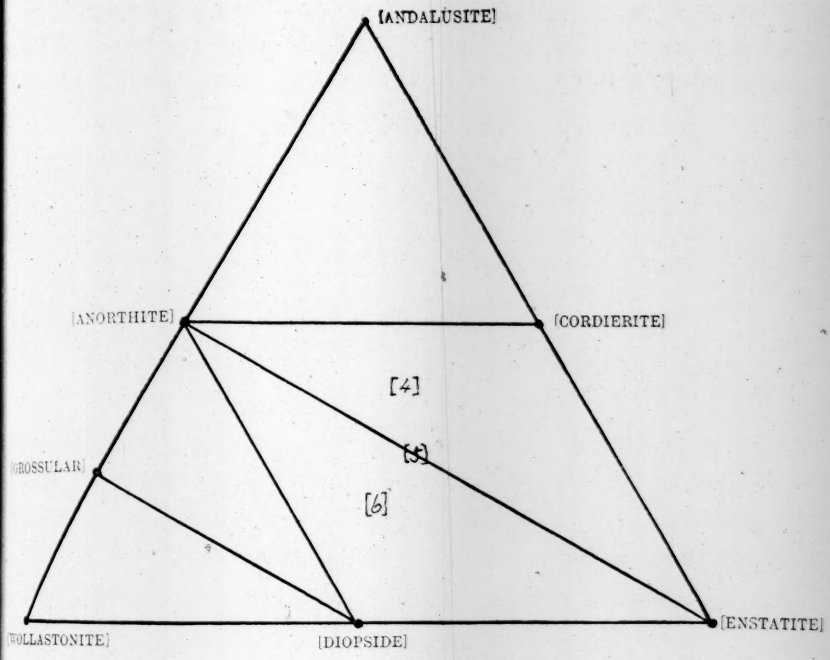


FIG. 1.—Shale-limestone hornfelses.

The classification of the hornfelses of the Kristiania district as detailed by Goldschmidt is now well known, and in this place it will suffice to indicate the nature of the hypersthene-bearing hornfelses by reference to a ternary diagram in which the relations of the various hornfelses are concisely revealed. Such a diagram is represented in Fig. 1. It represents in reality the free-silica-hornfelses of the system, $CaO$-$MgO$-$Al_2O_3$, and in all of them quartz is present. It is here clearly indicated that by gradual increments in lime an ordinary shale or slate hornfels reaches the appropriate composition for hypersthene to figure as a mineral constituent. The three classes of hypersthene-bearing hornfelses in this diagram comprise :—

(*a*) Hypersthene cordierite plagioclase quartz.
(*b*) Hypersthene plagioclase quartz.
(*c*) Hypersthene plagioclase diopside quartz.

By further increase in lime hypersthene gives place completely to diopside.

Until quite recently hypersthene-bearing hornfelses were unknown from British contact zones, but they have now been found in contact zones from Scotland, in two areas, from the aureole of the Insch mass, Strathbogie, described by H. H. Read (5), and from the contact zones of the Carn Chois diorite, Perthshire, by the writer (6).

Hypersthene-hornfelses of the Kristiania type are comparatively abundant in the aureole of the Carn Chois intrusion, those with cordierite being especially characteristic.

However, hypersthene is developed in some of these hornfelses independent of the entry of lime, for plagioclase in these is either in very small amount or altogether absent.

From the standpoint of Fig. 1, these hornfelses are represented along the edge of the triangle and between the points representing cordierite and enstatite. As, however, lime is now excluded from the system, and moreover the potash minerals are abundant as constituents—these last minerals being excluded from the Goldschmidt classification—we may utilize a second diagram, which includes $K_2O$, $Al_2O_3$ and MgO, quartz as before being always present.

The partial diagram, Fig. 2, may represent these conditions. In this diagram the points for kaolin, sericite, and chlorite, the original constituents of the rocks, which react to give the various hornfelses, are inserted as far as this is possible in such a partial diagram. Biotite is represented on the line joining sericite and the magnesia apex.

If we divide this triangle as usual into the appropriate triangles conforming to the known mineralogical associations we obtain those numbered 1, 2, 3, 4, etc. As, however, this diagram does not rigidly represent a three-component system nor four with quartz, but is at least a five-component system, the minerals in adjacent triangles may be in equilibrium, but not those in triangles further separated. Thus we have the well-known hornfelses of the type: (*a*) Andalusite-orthoclase-cordierite-biotite-quartz, and the less frequent (*b*) Orthoclase-cordierite-biotite-hypersthene-quartz, but mineral combinations of the triangles 1 and 4 are not associated; thus andalusite and enstatite are not found together.

The triangle AEC may represent in general the compositions obtaining in ordinary shales, but if kaolin is not an original constituent, and the rock consists essentially of quartz, sericite, and chlorite, then the bulk composition is represented within the triangle CEF, or still more limited within C′EF′, considering the limited range of composition of the rock-making chlorites.

It will now be noted that the hornfelses 1, 2, and 4 are penetrated by the composition field of the original rocks.

Only the more magnesian sediments will give rise to hypersthene, and, as the MgO content falls or chlorite becomes less abundant, the hypersthene is gradually replaced by cordierite.

It is at once apparent, by comparing Figs. 2 and 1, that in rocks free from lime a much greater relative content of MgO is necessary for the production of rhombic pyroxene than in the lime-bearing types. This is brought out by a comparison of the MgO : $Al_2O_3$ ratios for hypersthene-hornsfelses in the two diagrams.

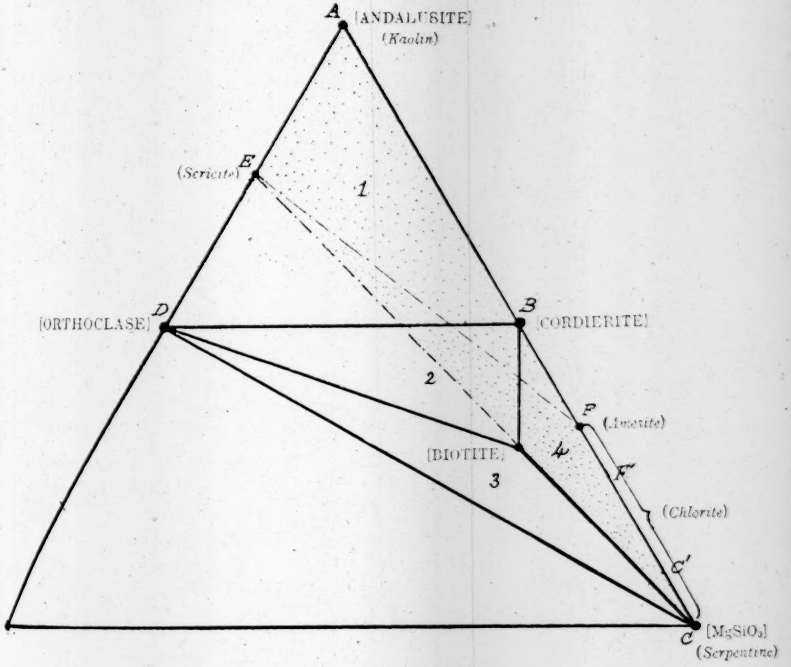


FIG. 2.—Non-calcic shale hornfelses.

Given in summary, we have among free-silica-hornfelses the following hypersthene-bearing types :—

| | | |
|---|---|---|
| 1. | Hypersthene cordierite plagioclase quartz biotite orthoclase . . . . . | calcic types. |
| 2. | Hypersthene plagioclase quartz biotite orthoclase . . . . . | |
| 3. | Hypersthene plagioclase diopside quartz biotite orthoclase . . . . . | |
| 4. | (*a*) Hypersthene biotite cordierite quartz. . | non-calcic types. |
| | (*b*) Hypersthene biotite cordierite orthoclase quartz . . . . . | |

It is of interest to note at this point that the original hypersthene-

hornfels described by Ramsay is of the non-calcic type and corresponds to type 4 (*b*) above.

Having thus considered the free-silica-hornfelses in which hypersthene figures, we may now turn to those hornfelses in which quartz is always absent. A deficiency of silica at once involves, in the case of the cordierite-bearing types, the entry of spinel in accordance with the relation

$$Mg_2Al_4Si_5O_{18} = 2MgAl_2O_4 + 5SiO_2.$$

The calcic hypersthene-hornfelses are represented then by such hornfelses as :—

5. Hypersthene cordierite plagioclase spinel biotite orthoclase.
6. Hypersthene plagioclase spinel biotite orthoclase.

and the non-calcic hornfelses by such types as :—

7. (*a*) Hypersthene biotite cordierite spinel.
   (*b*) Hypersthene biotite spinel.
   (*c*) Hypersthene biotite cordierite spinel orthoclase.
   (*d*) Hypersthene biotite spinel orthoclase.

Some of these occur in the contact zones of the Carn Chois diorite. In particular we may note a very beautiful example of 5, in which large hypersthene porphyroblasts enclosing numerous grains of green spinel are set in a base of cordierite, plagioclase, and biotite. There are no representatives of 7 among the non-calcic hypersthene-hornfelses of this area hitherto recorded.

### Biotite-free Hypersthene-Hornfelses.

In the hornfelses so far considered, biotite has been always present. There are, however, hornfelses of the preceding types in which biotite is only very sparingly present or altogether absent. Its presence appears to depend on the presence of relatively abundant water during metamorphism. If, as in some of the highest stages of metamorphism, the reacting system becomes deficient in this constituent, biotite will be represented by other constituents. Thus it may be represented by orthoclase, cordierite, spinel, and magnetite.

15 biotite = 30 orthoclase + 9 cordierite + 12 spinel + 20 magnetite, some of the ferrous oxide, being oxidized to ferric oxide, produces magnetite, as in the spinel-hypersthene-hornfelses.

If the system give a free-silica-hornfelses, quartz being present, the biotite will be represented by orthoclase, cordierite, and magnetite. Such biotite-free hornfelses occur in the Carn Chois contact zones. Thus, we have hornfelses of the type : (*a*) Hypersthene, cordierite, plagioclase, orthoclase, quartz, and (*b*) Hypersthene cordierite orthoclase quartz, which are otherwise identical with the hornfelses Nos. 1 and 4*b* given on page 413.

The relations of the silica-poor hypersthene-hornfelses can be expressed diagrammatically, as in Fig. 3.

In the partial diagram the dotted area represents the bulk compositions of shales whose constituent minerals are indicated by the points for quartz, kaolin, and chlorite.

In mixtures rich in chlorite, spinel-hypersthene-hornfelses with

cordierite are to be expected, but with increase in kaolin[1] hypersthene disappears, corundum may develop, and then andalusite ; finally spinel disappears and quartz enters, or, with increasing silica, spinel first disappears and ultimately quartz enters, giving a hornfels of Class 4 (calcic type), or a non-calcic type as No. 4 above. It would appear probable that hypersthene is more common in contact zones than descriptions would suggest. As in the Carn Chois contact aureole, it is frequently partially, and sometimes wholly, replaced by bastitic serpentine, its former presence might be overlooked

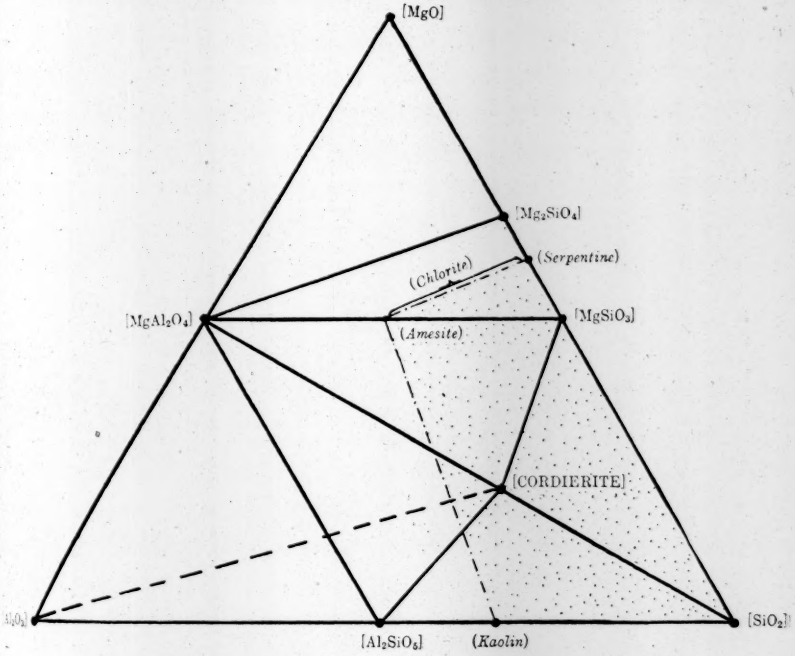


FIG. 3.—Hornfelses of system $MgO—Al_2O_3—SiO_2$.

should the replacement be complete. Careful search for serpentine pseudomorphs in hornfelses from other British contact zones may reveal examples of rocks of this type.

## RHOMBIC PYROXENE AND METAMORPHOSED CARBONATE SEDIMENTS.

Considering the ease with which the magnesite molecule dissociates to form periclase, or reacts with silica to give olivine, the apparent

[1] Sericite-chlorite mixtures cannot be adequately represented on this diagram, as $K_2O$ is not included. Sericite itself gives rise to orthoclase and corundum, and with chlorite to biotite, cordierite, and spinel. The succession of hornfels types, in passing from chlorite rich mixtures to sericite rich mixtures is therefore of the following nature : biotite-orthoclase-cordierite-hypersthene-spinel, to biotite-orthoclase-cordierite-corundum-spinel.

absence of the rhombic pyroxene in metamorphosed siliceous carbonate sediments is noteworthy. Among the usual minerals as listed developed in contact zones of dolomites, rhombic pyroxene is conspicuous by its absence.

In the ordinary type of carbonate sediment the MgO/CaO ratio is never greater than unity, i.e. the maximum is reached in dolomite. From Fig. 1 we see that, with further increments of lime, the free-silica hypersthene-hornfelses pass over into diopside types, a condition expressed by the equation

$$MgSiO_3 + CaSiO_3 = CaMg(SiO_3)_2.$$

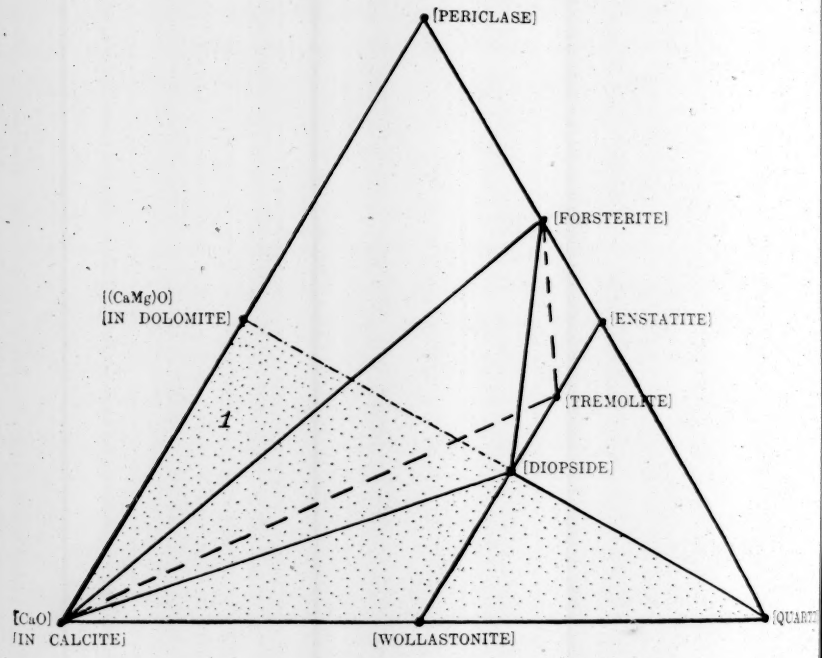


FIG. 4.—Carbonate-calc-magnesian silicate hornfelses.

It is clear that the right side of this equation is the stable one at all temperatures below the melting point, so that enstatite and wollastonite should not occur together. This is confirmed by petrographical observation.

We can, however, consider the question from the point of view of a magnesian limestone, with successive increments of silica, being subjected to metamorphism. The diagram (Fig. 4) may represent the conditions.

In this partial diagram—alumina being excluded—the composition of the carbonate sediments containing silica can be expressed by points within the dotted area, and the whole triangle can be divided

into the several triangles in accordance with the known mineralogical associations. The hornfels of type 1 is characteristic, for example, of dolomites with only a small proportion of silica. The composition of the remaining hornfelses can be obtained by projecting to the $SiO_2$ apex from a point within the triangle 1, so forsterite gives place to tremolite, diopside, wollastonite.

I know of no enstatite occurrences which might suggest the stability of the assemblages—calcite-forsterite-enstatite, or calcite-enstatite-diopside. From this diagram it appears that enstatite might arise from carbonate sediments containing magnesite. Metamorphosed sediments of this nature must, however, be exceedingly rare, if such exist at all. In normal carbonate sediments the presence of rhombic pyroxene appears to be inhibited by the presence of lime as calcite. This condition may be appropriately represented by ideal equations as

$$CaCO_3 + 3\,MgSiO_3 \longrightarrow CaMgSi_2O_6 + Mg_2SiO_4 + CO_2.$$
$$CaCO_3 + 5\,MgSiO_3 \longrightarrow CaMg_3Si_4O_{12} + Mg_2SiO_4 + CO_2.$$

tremolite arising under conditions of lower temperature.

### The Production of Rhombic Pyroxene in Thermally Altered Igneous Rocks.

Hypersthene may arise in the thermal alteration of igneous rocks, of which it was not originally a separate mineral constituent, or from the contamination of igneous magmas. The conditions under which it is generated in these cases may be very shortly considered. (*a*) Metamorphism of basic igneous rocks with monoclinic pyroxene; (*b*) metamorphism of basic igneous rocks with monoclinic amphibole; (*c*) contamination of igneous magmas.

In the pyroxenes produced by thermal alteration of sedimentary rocks, any noteworthy solid solution between the rhombic and monoclinic members has not yet been recognized, and no pyroxenes comparable with enstatite-diopside or enstatite-augite are found. They appear, in fact, to be limited to rocks of igneous origin.

When igneous rocks containing enstatite-augite as a constituent mineral are subject to high-grade metamorphism, a rearrangement of the pyroxene molecule may take place involving the setting free of rhombic pyroxene. The writer has described such a case in the metamorphosed dolerites of Eyre Peninsula, South Australia (7). The original monoclinic pyroxene contains $MgSiO_3$, in solid solution, and where highly metamorphosed the rock has developed hypersthene, diopside, and garnet.

The mechanism of this reconstruction was expressed by the equation:—

$$\begin{pmatrix} x\,CaMg(SiO_3)_2 \\ y\,MgSiO_3 \\ Al_2O_3 \end{pmatrix} = CaMg_2Al_2Si_3O_{12} + (x-1)CaMg(SiO_3)_2 + (y-1)MgSiO_3.$$

The original pyroxene is partially or wholly converted into a mixture of garnet, diopsidic pyroxene, and hypersthene. The felspar appears to play no part in this rearrangement.

A somewhat similar case is now revealed from the contact zones of the Carn Chois diorite. Where the great epidiorite sills and sheets of the Dalradian series become involved in the inner aureole of the intrusion, they suffer considerable metamorphism. Outside the aureole the epidiorite is essentially composed of hornblende and plagioclase felspar. When it enters the aureole, the rock is recrystallized, but close to the contact pyroxene is generated. The epidiorite is converted into a granular hornfels composed of plagioclase, green monoclinic pyroxene, pleochroic hypersthene, and magnetite. Both the pyroxenes and the magnetite arise regenerated from the amphibole. Simply expressed, this is a splitting of the metasilicate

$$CaMg_3Si_4O_{12} = CaMgSi_2O_6 + 2MgSiO_3,$$

the alumina of the original amphibole being absorbed into the monoclinic pyroxene, while part of the iron is converted to magnetite. The degradation of enstatite-augite into the two pyroxenes under thermal metamorphism may express the tendency under conditions favourable to the equilibrium state of very limited solid solution under the *P.T.* conditions in contact aureoles, such as is revealed in the pyroxenes of sediment hornfelses.

### Contamination of Igneous Magmas.

The production of hypersthene under these conditions calls for little notice here, as it has frequently been discussed elsewhere (8). We may distinguish two cases, (*a*) contamination of igneous rock by igneous rock, (*b*) contamination of igneous rock by sediment. Under (*a*) comes the well-known case of gabbro-granite hybridism, where, in the presence of free quartz, olivine is converted to hypersthene, and, secondly, where an aluminous pyroxene of the basic rock reacts with silica to give hypersthene and anorthite.

Similarly, the addition of alumina, in the form of cordierite or andalusite, from sedimentary contamination, to a gabbroic magma free from rhombic pyroxene, at once gives hypersthene, thus:—

$$Al_2SiO_5 + CaMgSi_2O_6 = MgSiO_3 + CaAl_2Si_2O_8.$$

The production of rhombic pyroxene to form contaminated norites, often cordierite-bearing, is well illustrated by the contaminated norites of Aberdeenshire and other regions. This question has been discussed shortly by the writer (9), and still more recently by N. L. Bowen (10), and calls for no further comment here.

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(9) C. E. Tilley, Geol. Mag., Vol. LVIII, 1921, p. 559; LIX, 1922, p. 235.
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## The Greenstone Ridge at Ty'n-y-coed, Radnorshire.

By H. G. Smith, B.Sc., A.R.C.S., East London College.

In an earlier paper (8) [1] an olivine-basalt was described from this locality; the present contribution may be looked upon as a continuation of the study then begun. This basalt is best exposed at the southern end of the ridge in a small quarry, but several exposures are to be seen farther north. All these, where the compact,

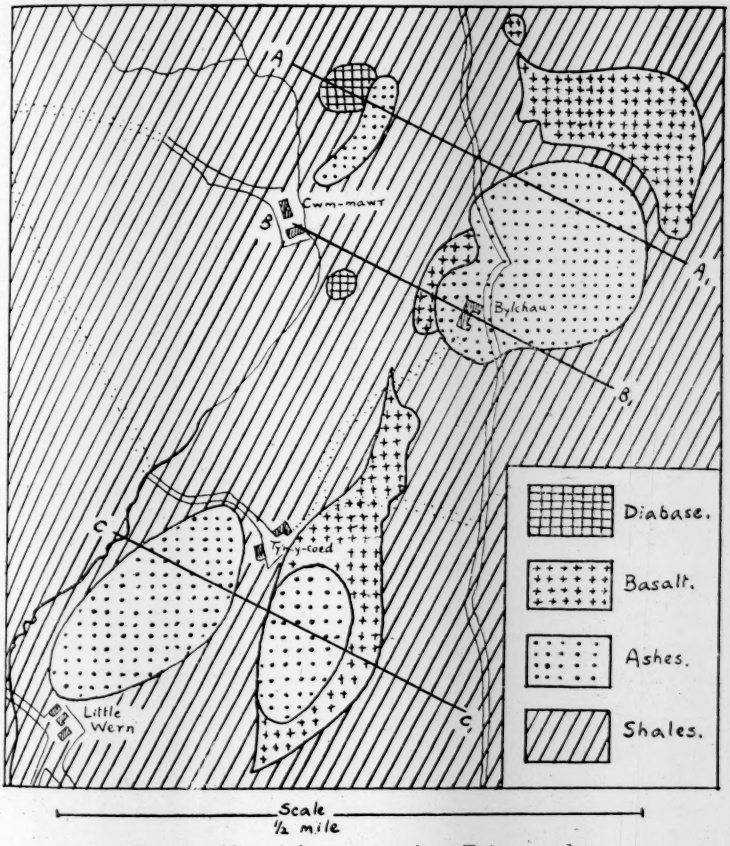


Fig. 1.—Map of the country about Ty'n-y-coed.

fresh-looking basalt is to be observed, are situated along or near the eastern margin of the ridge, a fact particularly well shown near the northern end. On the western side of this strip are several exposures of fine-grained, brownish rock, so well jointed that it is almost impossible to get a good specimen; an additional feature of importance is that the exposed surfaces are frequently striated.

[1] Figures in parentheses refer to bibliography at end of paper.

That these striations are not of glacial origin is demonstrated by their occurrence on newly-quarried surfaces, and also by the fact that specimens bounded on two sides by these striated surfaces may be collected.

Thin sections of this rock show much alteration, but numerous laths of plagioclase felspar with refractive index higher than that of Canada balsam may be recognized; these are associated with pseudomorphs preserved in a green substance polarizing in first order colours, sometimes as an aggregate, each individual showing a black cross in polarized light—a character commonly found in chlorite. Some of the pseudomorphs are six-sided, exhibit two smaller and four larger angles, and must represent olivine. Ilmenite occurs as opaque skeletons showing white in reflected light. Some of the felspars are replaced by a yellowish-green substance with a fairly good relief and polarizing in low colours; this is possibly a member of the epidote group. Calcite is a common alteration product. There is a green groundmass. A section cut parallel to the direction of the striations and at right angles to the striated surfaces shows numerous cracks traversing it in all directions; some of these contain a fibrous green substance, the fibres being sometimes, but not always, parallel to the cracks. The polarization colours are sometimes fairly high, but the mineral is considered to be chlorite.

It is not possible in the field to draw a line between this crushed rock and the basalt; there appears to be a perfect gradation, and it is considered that the two are one and the same, the western variety having been affected by faulting—something in the nature of a crush-breccia. This crushed rock occupies some of the highest ground, and its asymmetrical distribution in the ridge suggests that a thrust has moved the overlying rocks, now largely denuded, from west to east.

The basalt, however, has not been displaced with reference to the associated shales. These latter rocks are well seen near the path connecting Bylchau and Ty'n-y-coed along the western margin of the basalt just before its northern termination. Here the shales dip to the west, and it is extremely probable that they overlie the basalt. Unlike the shales commonly met with in the district, they contain distinct micaceous flakes; on the whole they are harder and blacker than usual, and, what is probably the most significant point, they have in places lost their fissility. Fortunately, it is possible to examine these shales in several good, small exposures, the rocks having been exposed in consequence of the explorations for coal which supplied Murchison with an opportunity to indulge his talent for caustic criticism (1, p. 328). These shales yield tuning-fork graptolites.

As has been pointed out, the shales overlie the basalt and show the effects of heating; when it is added that the acute-angled terminations of the igneous rock near the shale exposures just

mentioned, and also east of the road running north from Bylchau, are perfectly diagrammatic on the ground, it would appear that the intrusive nature of the basalt is established beyond question.

The covering rocks of the period of intrusion are not necessarily represented in the ridge at present. No metamorphic effects have been observed in this cover, but there are two good reasons why these should not be expected; one is that the rocks are pyroclastic and the other is that we have seen reason to suppose that the cover has been thrust towards the east, bringing on to the present ridge rocks which were possibly beyond the region of intrusion. That such movement has been effected is undoubted; the question of its magnitude, however, remains to be settled. It may be merely the result of a slight adjustment consequent on the folding of the overlying rocks to form the general anticlinal structure, but possibly it is something much more important.

It will be seen, on inspection of the old Survey map, that west of the ridge are several small arcs, also mapped as greenstone. The two arcs near the southern end of the ridge are formed of well-bedded ashes from which graptolites have been obtained. These ashes dip steeply to the west and the arc-like form is just the sort of character to be expected if the ashes have been shifted as the result of the thrust previously suggested. The eastern arc near the northern end of the ridge is also an ash, the western one being an intrusive rock to be considered presently. Ashes are also observed in the vicinity of Bylchau along the main ridge of "greenstone", and fragments of ashes may be obtained from a ploughed field near the southern limit of the ridge.

The pyroclastic rocks about Bylchau occupy lower ground than the basalt and have probably been pushed over a basalt-shale surface into their present position between the pre-existing hummocks of basalt; it is not considered that any considerable mass of the latter rock has been moved. On the ground, these pyroclastic rocks are in places obviously fragmental, but some varieties are finer-grained and sometimes exhibit a spheroidal aspect which is considered to be an original character. In thin section, the coarser variety is a typical tuff containing fractured, angular fragments of plagioclase felspar as well as others which appear to have been ejected as complete well-formed crystals. There are also fragments of igneous rocks of somewhat varied types, mostly angular, but a few showing perfect rounding. All contain plagioclase too much altered for a refractive index test, but judging by the very common low extinction angles, the mineral is not one of the more basic varieties. Some examples consist almost entirely of laths of felspar which either have no definite orientation or exhibit a sub-parallel arrangement; these crystals are set in a chloritic groundmass which forms the rest of the fragment. In other cases the felspar crystals are only slightly elongated and are scattered through the fragment in which there is a great abundance of groundmass;

also embedded in this are green pseudomorphs with a form reminiscent of augite and aggregates of black specks with a form suggesting derivation from hornblende. The boundaries of these fragments cut indifferently across crystals and groundmass. In addition, there are quite irregular glassy fragments containing well-formed crystals of felspar; the glass transmits a yellowish-green colour, and is in places distinctly vesicular.

Such a breccia has probably acquired its characters as a result of the eruption by which it was formed; in the vicinity of a plane of movement some of the brecciation may be of later date, but no evidence of this has been observed.

The ash above Cwm-mawr is of a very different type. It is a grey, well-bedded rock, very fine grained on the whole, but containing curious ovoid bodies with a maximum dimension of about half an inch, as well as much smaller bodies which appear as dark specks; there is a marked difference in the two sizes. In thin section the rock consists mostly of an aggregate of extremely angular fragments, commonly tri-radiate; a few slightly larger individuals may be identified by their form as comminuted fragments of vesicular glass. These have been devitrified. Embedded in this aggregate are a few well-formed crystals, now pseudomorphed, but probably originally felspar. The dark specks are seen in thin section as dark brown patches, many of them approximately circular, some elongated, but all of them with indented margins, in a few cases moulded on the embedded crystals, sometimes on the cusps of glass; in a few examples the cusp is shared by the brown patch and the general body of the rock. Some of these dark areas include fragments of felspar crystals. It is suggested that these bodies were formed of viscous material ejected from the vent, and that they were soft enough at the time of accumulation to be indented by any hard object with which they came in contact. The larger ovoid bodies are apparently similar in mode of origin. They appear in hand specimen to be bounded by a perfectly sharp line, but in thin section are seen to be slightly indented, though not so much as in the case of the smaller examples. Possibly a more violent phase of the eruption caused these larger individuals to be thrown to a greater distance from the vent than usual; this would mean a longer aërial journey for the larger bodies, more complete cooling, and hence the smaller amount of indentation on deposition. Recognizable small fragments of felspar are included in a fine-grained base.

The graptolitic ashes south-west of the ridge are well bedded, showing distinct alternations of narrow light and dark grey bands. No bed exactly comparable with that above Cwm-mawr has yet been observed here, but in thin section there are some points of resemblance. Again the rock is built largely of broken vesicular glass, but no undoubted lapilli are represented, certainly none of the larger examples. Another difference is supplied by the abundance

of small angular fragments of felspar, most of them showing twin striations.

A loose fragment collected near the southern end of the ridge includes ash of two types, one fine grained and black, the other grey and distinctly coarser. A section across the junction shows that the finer ash is made up of very minute angular fragments of felspar, together with flakes of a white mica embedded in a still finer base. The coarser half of the same specimen is very similar to that already described from near Bylchau, angular fragments of felspar and felspathic lavas being associated. The occurrence of the two varieties is to be accounted for by eruptions of greater and less violence.

The intrusive rock above Cwm-mawr is a diabase very similar to those previously described from this area. Much of the rock is made up of mutually interfering broad laths of plagioclase felspar almost too much decomposed to show the twin lamellæ ; the angles of extinction indicate a composition approximating to acid labradorite. Undecomposed constituents are needles of apatite and some residual augite of a pale brown colour. This latter constituent is moulded on the felspar, but is not sufficiently abundant to produce good ophitic structure ; it is associated with a green mineral which is probably a result of its alteration. The most striking constituent of the rock is ilmenite. It is seen in fairly large masses moulded on the felspar and also on the green alteration product. Even in transmitted light it shows the characteristic geometrical patterns of black lines with intervening altered areas, while in reflected light this alteration-effect is beautifully exhibited. A specimen collected from the slope below exhibits some points of resemblance. Again the bulk of the rock is made of laths of felspar and there is much ilmenite and apatite. The rock is finer grained and there is no fresh augite ; there is, however, some green alteration product. There is a fair amount of calcite replacing some original constituent, but form in this case does not supply a very useful guide to identity. Some pyrite is present. There is also much transparent interstitial material.

South-east of Cwm-mawr, near the brook, occurs another exposure of a very similar rock. It resembles that last described, but is finer grained. The transparent interstitial material has a low refractive index, in some cases almost exactly equal to that of Canada balsam, is penetrated by slender colourless needles with a hexagonal cross-section, probably apatite, is idiomorphic towards the calcite, contains cavities enclosing bubbles, occasionally exhibits suggestions of cleavages, polarizes in greys and yellows, the latter higher in Newton's scale than those of the felspar, shows what appear to be good examples of simple twinning, and gives an indefinite interference figure which appears to be uniaxial and positive. It does not appear possible to include these characters in one mineral, and probably both quartz and albite are present.

This ridge at Ty'n-y-coed, then, is considered to have a shale foundation with a capping of ashes. At the junction the different igneous rocks have been intruded. On account of the fact that the basalt has been crushed while the diabase has not been shown to be affected, the former rock is considered to be the older. Further work, however, is necessary to establish this point. The question of the form of the basalt intrusion is a separate problem. In the earlier paper (8) the intrusions of this area were considered to have been injected from below, the possibility of lateral injection being ignored. It will be seen that one of the sections across the ridge shows that the idea of lateral or downward intrusion is accepted in the case of this basalt. There are, of course, numerous recorded examples of such intrusions (one of the earliest of these was described by Judd (4, p. 138) in 1875), and, fortunately, there is in this district

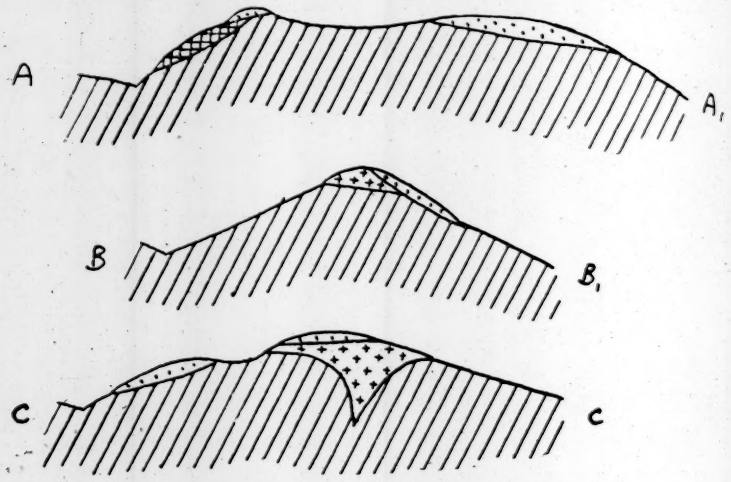


FIG. 2.—Sections along the lines indicated on the map.

an example which exhibits the shale foundation very perfectly. This is a diabase situated about mid-way between Ty'n-y-coed and Gelli Hill. The intrusion has a north-south trend and is crossed by several small streams feeding the brook that flows to the south past Little Wern. These streams have cut deep notches in the hillside, and careful mapping shows that the fairly broad band of diabase between the streams becomes narrower as one descends; one of the streams has cut completely through the diabase, and now flows entirely over shales. It is suggested that intrusion took place between shales and some covering rock which rested with a discordance on its foundation, and that the magma succeeded in forcing its way downward between the shale beds. The development of anticlinal structure in the higher beds might necessitate the opening of the bedding planes in the steeply dipping underlying

shales, and any available magma would tend to occupy the spaces thus formed.

Many of these intrusive masses have acute-angled terminations, but some of them end rather aimlessly in a few scattered blocks which are considered to represent the floor of an intrusion at a point where it had failed to find a lodgment between the underlying shale beds. The intrusive mass of Castle Bank described by Mr. Woods (5, p. 576) is an example with a very definite acute termination at its southern end, but it spreads out in a somewhat bulbous manner to the north.

Successive intrusions at an unconformable junction at which there have been movements of some considerable magnitude are considered most satisfactorily to explain the phenomena presented by this region.

As additional evidence of the existence of a crush-zone in this area, it may be pointed out that at intervals round the base of Gelli Hill, which is a pile of ashes resting on shales, there are exposures of breccia. Not one of these in itself is convincing, since in most cases there is no proof that brecciation followed deposition, but there is one example of a crushed conglomerate which certainly does supply evidence of earth-movement. This is found on the eastern side of the hill and is perhaps open to the suspicion of being an erratic block; if so, it is a remarkable coincidence that has caused its stranding just at a point where a crushed rock might be expected.

This conglomerate has black, white, and pink pebbles of various sizes, but few being more than 1 inch in diameter, embedded in a hard grey cement. The rock has a distinct fissility, and several sections were cut at right angles to this direction. Examination of these shows that the rock is made up largely of quartz, but there are fragments of volcanic rocks and a few of felspar. The volcanic material contains in some cases numerous laths of felspar; in others, there are a few little-elongated felspar crystals embedded in a glassy base. Almost invariably these allothigenous constituents are angular, not as a result of their mode of accumulation, but because of changes which have taken place since deposition and consolidation. They exhibit many sub-parallel cracks, and their margins, where in contact with quartz, are indented. In fact, the volcanic fragments have been kneaded in consequence of the pressure to which the conglomerate has been subjected. The quartz grains themselves have frequently the form of augen, tailing away at the ends into strands of what appears to be micaceous material. Occasionally they exhibit ghosts of original grains with clear peripheral quartz, indicating that cementation preceded crushing; there appears to be no reason to suppose that formation of the peripheral quartz resulted from crushing. The grains frequently exhibit undulose extinction and have sometimes been shattered with deposition of secondary silica along the cracks.

The felspar fragments have been less successful in retaining their identity; some of them are obviously residues; they are very angular and tail away into good colourless mica. Some examples of faulted twin lamellæ are to be observed, but in no case is there anything to suggest that twinning is the result of pressure. In some cases the felspar is indented by grains of quartz. These results are in general similar to those produced as a result of the Moine Thrust in the N.W. Highlands of Scotland (7, p. 597), but there are some differences, notably in the comparative effects on quartz and felspar.

Judging by the position in which this conglomerate is found, at the junction of ashes with underlying shales, it fits into the structural scheme suggested by the study of the Ty'n-y-coed ridge. The volcanic fragments found in it are remarkably similar to those of the district, and it would appear therefore that these have contributed to the rock in consequence of the ordinary processes of denudation and deposition. In connexion with the age of this conglomerate, it may be mentioned that Upper Llandovery rocks occur on both sides of this upland region (6, p. 229; and 8, p. 503), and that they dip away from it in both cases. It would appear that the movement was, in part at least, post-Llandovery, and as diabase to the east has been shown to be later than these deposits, there are some of the data for a connected account.

This work has been facilitated by a grant from the Dixon Fund administered by the University of London; for this the author tenders his thanks.

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# REVIEWS.

EARTH EVOLUTION AND ITS FACIAL EXPRESSION. By WILLIAM HERBERT HOBBS. pp. i–xvii, 1–178, with 6 plates and 84 figures in the text. New York: The Macmillan Company, 1921. Price 15*s.* net.

IN this volume Professor Hobbs collects and summarizes his ideas with regard to the evolution of the earth. It is a subject on which no two thinkers are likely to agree, and accordingly it is not surprising to find that most of his conclusions are open to criticism.

He begins by rejecting the nebular hypothesis altogether, but his examination of it is far from complete. There can be no doubt that Laplace's form of the hypothesis requires important modifications; but nevertheless it seems likely that it has some foundation in fact. Those who wish to know how far it conforms with our present knowledge of the universe can hardly do better than read the very interesting Halley Lecture delivered by Dr. Jeans[1] at Oxford last year.

Having abandoned the nebular hypothesis, Professor Hobbs adopts a modified form of the planetesimal hypothesis of Chamberlin. He believes that at an early stage in its history the earth was represented by a swarm of meteorites moving in elliptical orbits—presumably approximating to the present orbit of the earth—all in the same direction but at different rates. He divides these meteorites into two classes, the iron meteorites with a density of about 5·6, and the stony meteorites with a density of about 3·6. The core of the earth is formed of a mixture of the two, but only the core. If a heavy meteorite collides with a lighter one, moving in the same direction, but at a lower speed, it imparts to the latter a velocity greater than its own. The author concludes that in time these collisions will drive the stony meteorites out of the orbit, while the iron meteorites will remain. But it is a question of mass, not of density; and it would be quite as reasonable to suppose that the smaller meteorites will be driven out and the larger ones left. Moreover, it should be borne in mind that as soon as the speed of a meteorite is increased its chance of being retarded by collisions with those in front of it is also increased. Professor Hobbs does not consider these difficulties; but he infers that the interior core, of iron and stony meteorites mixed, will be surrounded by a denser envelope composed of iron meteorites alone. Other

[1] There is also a semi-popular paper on "The Present Position of the Nebular Hypothesis" by Dr. Jeans in *Scientia* for October, 1918. The mathematical investigations will be found in his *Problems in Cosmogony and Stellar Dynamics*.

meteorites, from external regions, still fall upon the earth, and, according to the author, they belong chiefly to the stony class. Consequently, the dense layer of iron meteorites is surrounded by an outer envelope of stony meteorites. Finally, there are the sedimentary deposits, which at their thickest form no more than a thin skin.

By far the greater number of the ordinary igneous rocks are of lower density even than the stony meteorites. Therefore, according to Professor Hobbs, they cannot be derived from any great depth, and they must have been formed by the fusion of portions of the sedimentary skin. In support of this view, he compares the average composition of igneous rocks with the average composition of shales, and finds that there is very little difference. The average igneous rock contains rather less silica and rather more lime and soda; but these differences can be accounted for in several ways, and Professor Hobbs evidently looks upon the similarity of composition as a proof that the igneous rocks have been formed by the melting of shaley beds. It might equally well be considered a proof that the shales have been formed by the disintegration of igneous rocks.

The melting of the shales is supposed to take place where a strong bed is arched upwards by earth movements, and thus relieves the shales beneath it from the superincumbent pressure. A laccolith, according to the author, is not the cause of the accompanying dome-shaped uplift, but the uplift is the cause of the laccolith, and the igneous mass is produced by the melting, almost in situ, of the shales in the hollow of the dome. He says that no feeder to a laccolith has yet been found, and no dykes from a laccolith break into the arch above in the fashion that might be expected if the arch were in the state of tension required by the ordinary hypothesis. It is difficult to understand how he came to make either of these statements, especially the latter. In Mount Holmes and Mount Ellsworth these dykes are the only portions of the igneous intrusion that are visible.

Professor Hobbs is a supporter of the tetrahedral theory, with modifications. Like most supporters he ignores the essential difference between a rotating and a non-rotating sphere. To show that in certain circumstances the latter will tend towards the tetrahedral form is not a sufficient proof that in the same circumstances a rotating sphere will do the same. Apart from this, Professor Hobbs's modification introduces special difficulties of its own. At the end of the Eozoic era his tetrahedron was a simple tetrahedron with four corners, at the end of the Palæozoic era it was a twinned tetrahedron with six, and at the present time it is again a simple tetrahedron with four. Anyone who has tried to restore a battered tin to its original shape will know that in general it is easier to increase a dent or a ridge than to reduce it, especially if we are restricted to the use of compressive forces. The illustration is imperfect, but it would certainly require a remarkable arrange-

ment of forces to produce the changes that Professor Hobbs imagines.

One further point may be referred to. Suess imagined that many of the great mountain ranges are the crumpled edges of scales of the earth's crust which have been pushed over the part in front of them. Owing to the spherical shape of the earth, the edges of these scales are necessarily more or less circular, and the mountain ranges accordingly take the form of arcs. Professor Hobbs assumes that at each point of the range the force producing the movement must be at right angles to the arc, and therefore he supposes that Suess's explanation requires a system of forces radiating outwards from the centre of the arc, and at this centre there must be tension. To push a scale of the earth's crust over the part in front of it does not require a radiating system of forces, and in this respect at least Professor Hobbs has entirely misrepresented the views held by Suess.

These are the principal theses maintained by Professor Hobbs, and considerations of space prevent any fuller account of their development. The reader will find his book interesting and provocative of thought; and whether the author is right or wrong, these are considerable merits.

P. L.

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Post-Cretaceous Climates of South Africa. By A. W. Rogers, Sc.D., F.R.S. South African Journal of Science, vol. xix, 1922, pp. 1–31.

FOR his Presidential Address at the Lourenço Marques meeting of the South African Association for the Advancement of Science, Dr. Rogers chose the interesting subject of post-Cretaceous variations in the climate of South Africa. The address, which is here reprinted in full, contains an immense amount of information on the geological history of the sub-continent in its later stages, and the text is further illustrated by a very large number of additional notes and references. The general conclusions are that during post-Cretaceous times the climate has fluctuated within rather narrow limits, and that there has not been a Pluvial period. A general lowering of temperature during the Pleistocene may have given some of the Karroo and Kalahari rivers longer periods of flow, but no confirmation of the supposed existence of Pleistocene glaciers has been found by the Geological Survey, and Professor Daly and Dr. Wright, during their recent visit to the Mont aux Sources region, the highest mountain area in South Africa, found no such evidence. South Africa, like North Africa, both Americas, and Australia, bears witness to a shifting of the climatic belts in Pleistocene and subsequent times.

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Quartärgeologische Beobachtungen auf Sylt. By V. Nordmann, K. Jessen, and V. Milthers. Meddel. Dansk. Geol. Forening, vol. vi, No. 15, 1923.

A careful study of the Quaternary deposits of the island of Sylt, as described in detail in this memoir, has led the authors to the conclusion that the North European succession should be divided not as usual into three series, but into a fourfold scheme corresponding to the accepted succession of glacial and interglacial periods in the Alps and in North America. The oldest glaciation and the first interglacial period are represented in North Germany and Holland; the second glaciation is responsible for surface moraines in Holland and Oldenburg, and moraines below the Eem beds and marine diluvium in South-West Jutland. The second interglacial period can be traced in Holland and the Frisian Islands, and is represented by marine diluvium at Esbjerg. The third glaciation formed surface moraines and underlying gravels in South-West Jutland, in Sylt, in West Holstein, and in places between the Elbe and the Weser. The last interglacial period is shown by sand-covered peat bogs at Brörup and in other places, and submarine peat in Sylt, while the last glaciation originated the surface moraines in East Jutland and East Holstein.

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Die Kriegsschauplätze 1914–1918 geologisch dargestellt, Heft 4: Vor Verdun. By Dr. F. Sturm. Breslau, pp. 44. Berlin: Borntraeger, 1923.

Section 5 of this work, on Argonne and Champagne, has already been reviewed in the Magazine. The present instalment comprises a geological description of part of the eastern border of the Paris Basin, consisting of strata ranging from the Bathonian up to the lower beds of the Cenomanian (Argonne Sandstone), which are only found west of the Meuse. Besides a detailed account of the stratigraphy and palæontology of the regions, sections are devoted to the physiographic features, underground water and rivers, and economic products, the latter being of little importance, as the limits adopted just exclude the iron ore field of Longwy.

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# REPORTS AND PROCEEDINGS.

## Geologists' Association.

*Friday, 6th July,* 1923.

"The Superficial Deposits of South Buckinghamshire and South Hertfordshire and the Old Course of the Thames." By R. L. Sherlock, D.Sc., A.R.C.Sc., F.G.S.

The supposed Pliocene deposits on the north side of the Thames are discussed and reasons given for regarding them as Reading Beds and the others as early Pleistocene. These latter, together

with the Clay-with-flints and associated Pebbly Clay and Sand, are considered to be formed by local ice and snow, somewhat earlier than the deposits usually regarded as Glacial. The three deposits differ only lithologically, having been derived from somewhat different strata.

Glacial channels are described in the Chiltern Hills, and the Chiltern Gaps are considered to have been cut by streams from the glacier which was retreating northwards from the Chilterns and damming up lakes between the ice and the hills, as on F. W. Harmer's hypothesis.

The pre-Glacial course of the Thames is described between Bourne End and Ware, via Beaconsfield, Watford, Hatfield, and Hertford, and the river is traced up to its source (the present Kennet) and down to its mouth in the Wash, near King's Lynn. The Goring Gap is believed to have been non-existent and the Upper, or Isis, Thames was an independent river. The Kennet-Thames was plugged up by Glacial deposits, below Bourne End, and the present Thames, beyond Bourne End, and the Colne, were cut. Laminated, or Varve, Clays at Ware indicate a Glacial Lake there, and this is believed to have cut the Amwell Gorge and thereby produced the present River Lea.

Above the Varve Clays is the main Boulder Clay, indicating a readvance of the ice; and it is suggested that the gravels formed by the melting of this ice are of the age of the Boyn Terrace gravels, thus connecting Glacial and River Gravels.

## OBITUARY.

### Sir Henry Hoyle Howorth, K.C.I.E., F.R.S.

BORN 1ST JULY, 1842. DIED 15TH JULY, 1923.

The death of Sir Henry Howorth has removed a notable figure from among English geologists. A man of many parts, he was keenly interested in natural science, and, in his latter years especially, devoted much attention to geology. His knowledge was encyclopædic and he was a keen controversialist, but he lacked some of the qualities which go to the making of a great geologist. In his various geological writings he consistently upheld the importance of water-action as opposed to ice-action in producing various phenomena connected with the drift-deposits, and though he was an ingenious advocate, yet at the time of his death he was probably alone in his beliefs concerning the origin of these drifts.

His books are a storehouse of facts, and in the voluminous footnotes are useful references to the work of others. His principal geological works are "The Mammoth and the Flood", "The Glacial Nightmare and the Flood", and "Ice or Water?" Three volumes of the last-named were announced, but only two appeared.